RISK ASSESSMENT TECHNIQUES

5

Defense Systems
Management College

First Edition
July 1983

Fort Belvoir,
Virginia 22060

A HANDBOOK FOR PROGRAM MANAGEMENT PERSONNEL

WHAT IS RISK ASSESSMENT?

WHY DO A RISK ASSESSMENT?

WHAT TECHNIQUES ARE AVAILABLE?

HOW DO I SELECT A TECHNIQUE?

HOW DO I IMPLEMENT?

This handbook was prepared by Information Spectrum, Inc., Arlington, Va. under Contract No. MDA 903-82-G-0055. The contract was supervised by the Defense Systems Management College, Fort Belvoir, Virginia. The views and opinions contained herein are those of the authors and should not be construed as an official Department of Defense position or policy unless so designated by other official documentation.

RISK ASSESSMENT TECHNIQUES

A HANDBOOK FOR PROGRAM MANAGEMENT PERSONNEL

I THINK CHANCE IS A MORE FUNDAMENTAL CONCEPTION THAN CAUSALITY; FOR WHETHER IN A CONCRETE CASE A CAUSE-EFFECT RELATION HOLDS OR NOT CAN ONLY BE JUDGED BY APPLYING THE LAWS OF CHANCE TO THE OBSERVATION.

MAX BORN
NATURAL PHILOSOPHY
OF CAUSE AND CHANCE

DEFENSE SYSTEMS
MANAGEMENT COLLEGE
FORT BELVOIR, VIRGINIA

FIRST EDITION
JULY 1983

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

HANDBOOK ORGANIZATION

1 INTRO

2 WHAT IS RISK ASSESSMENT?

3 WHY DO A RISK ASSESSMENT?

4 WHAT TECHNIQUES ARE AVAILABLE

5 HOW DO I SELECT A TECHNIQUE?

6 HOW DO I IMPLEMENT?

APPENDICES A - L

This Handbook has been written for those program management personnel who have an interest, but little (if any) prior experience in accomplishing a quantitative risk assessment of an acquisition program. Thus, the Handbook is organized to provide the "layman" with an overview of risk assessment as applied to defense acquisition programs in the first six chapters. Supporting details are provided in the Appendices.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

The primary objectives of this handbook are to make the reader aware of the risk assessment techniques being used by Department of Defense organizations, to alert the reader to the advantages and disadvantages of these techniques, and to assist him 1/ in applying risk assessment to his acquisition program.

The handbook is intended to be a practical guide and reference for program management personnel - not a textbook dealing with the theories supporting risk analysis, nor a user's manual for applying any particular techniques. Thus, the handbook is organized to address, in summary, the most important questions to program management personnel, i.e., Why do a risk assessment? What techniques are available? How do I select and implement a technique? These questions are answered in the first six chapters. This summary-level material is supported by a series of Appendices that provide detailed discussions of the techniques in use, the service regulations pertaining to risk assessments, a glossary of terms, and a structured bibliography.

Much of the basic information contained in this handbook was collected during a survey of program management offices and other service acquisition activities. The time that individuals in these offices allocated from their busy schedules to answer questions, locate related documentation and provide follow-up data should be recognized and appreciated by those who make use of this handbook. The Defense Systems Management College (DSMC) extends a "thank-you" to these individuals.

1/ Whenever in this handbook "man," "men," or their related pronouns appear either as words or parts of words (other than with obvious reference to named male individuals), they have been used for literary purposes and are meant in their generic sense.

The research and authorship of this handbook was carried out by Information Spectrum, Inc., under contract to DSMC. We recognize that this first edition may identify areas where addition or modification might enhance the utility of this handbook and that, as research in this field progresses, revisions may become necessary. Therefore, tear-out sheets have been provided at the end of the handbook for use by anyone desiring to make comments or suggestions for future revisions. Address your comments to: Research Directorate, DRI-R, Defense Systems Management College, Ft. Belvoir, VA 22060.

Edward G. Ingalls
Project Manager for the Handbook

INTRODUCTION

CHAPTER I

INTRODUCTION

A. PURPOSE AND APPROACH

Former Deputy Secretary of Defense Frank C. Carlucci, III, published a memorandum shortly after taking office in March 1981, with the objective and title of "Improving the Acquisition Process" (reference [1]).[1] This memorandum included 32 "initiatives". Initiative Number 11 required Department of Defense (DOD) action to increase the visibility of technical risk in budgets of weapon systems acquisition programs. Specifically, the memorandum required the Services (among other things) to "Incorporate the Use of Budget Funds for Technological Risk", and recommended an increase in "DOD efforts to quantify and expand the use of budgeted funds to deal with uncertainty". This handbook, therefore, has been written to familiarize program management personnel with the concepts and techniques of quantitative risk assessment, the conditions under which different techniques are appropriate, what resources are required, what assistance the different techniques provide, and what administrative procedures are prescribed for accomplishing quantitative risk assessment.

This handbook is intended to provide program managers[2] with a practical guide into this highly technical area, so that they will see the value of using formal quantitative risk assessment to assist them in internal management decision-making and in explaining their programs to higher review levels.

The methods used in this handbook to accomplish its purpose are first, to present a simplified explanation of the theory behind formal quantitative risk assessment; second, to

---

[1]Bracketed numbers in the text indicate references listed at the end of respective chapters.

[2]For brevity the term "program manager" will be used for either "program", "project", or "product manager", or for "program coordinator", "project engineer" or other variants.

demonstrate to program management personnel that they will find quantitative risk assessment advantageous to use; third, to describe individual techniques at a level of detail permitting appreciation and intelligent selection (but not necessarily personal utilization); and last, to inform program mnagement personnel of considerations relating to obtaining the support they may need to undertake an assessment.

B. SCOPE

Risk analysis has been defined (e.g., reference [2]) as a concept naving a broader definition than that of risk assessment,[3] encompassing risk assessment, risk reductions, and risk management, as shown in the right side of Figure 1. The figure shows one way of viewing the role of risk assessment in program management.

This handbook addresses formal, quantitative assessment of program risk,[4] generally leaving the creation and selection of risk-reducing program alternatives and the implementation and control of the selected alternative(s) to other guidance sources.

Since the motivation for this handbook is Mr. Carlucci's initiative on budgeting for technological risk, the emphasis will be on methods which assist in the formation of budgets. However, the interdependence of schedules, technological developments, and costs necessitates some discussion of risk assessment methods concerned with all three.

---

[3] Risk assessment will be described in Chapter II.

[4] Note that safety, or risk of accident, is not a addressed in this handbook.

PROGRAM MANAGEMENT RESPONSIBILITIES

PLANNING

EVALUATION
Risk Assessment

ALTERNATIVE CREATION

ALTERNATIVE EVALUATION
Risk Assessment

ALTERNATIVE SELECTION
Risk Reduction

IMPLEMENTATION
Risk Reduction
Risk Management

RISK ASSESSMENT

RISK REDUCTION

RISK MANAGEMENT

RISK ANALYSIS

Figure 1

RISK ANALYSIS COMPONENTS

This handbook is intended to be a reference and guide for program management personnel. If, at times, liberties are taken with mathematical rigor, it is for the purpose of clarifying concepts for people who must absorb and appreciate them enough to decide on employing them, but need not attain the analyst's requirement for rigor or for understanding of subtle issues of theory. The reader who wishes to pursue any of the topics introduced herein can find depth, rigor, and interesting exposition in the works designated as "core" (indicated with an asterisk) in the bibliography, Appendix A.

C. SOURCES

The statements made in this handbook regarding practical considerations in the acquisition environment are derived from an extensive survey of program management and analytical support offices in the military services. The offices were selected to represent a wide range of technologies, management office "strengths", technical complexities, costs, and maturities. More

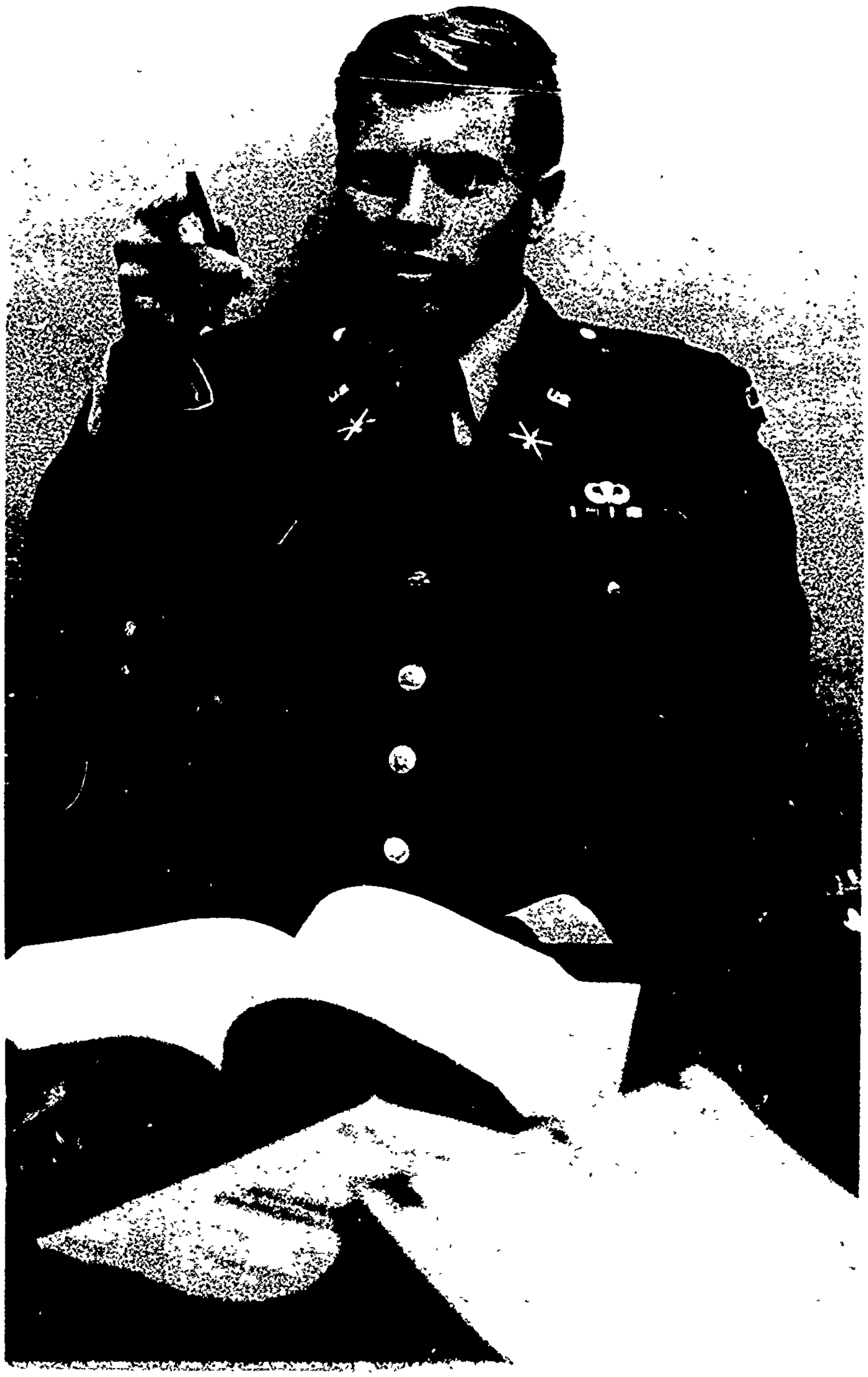
than 40 program offices, 8 analytical support offices, various headquarters within DOD, and academic and industry researchers, constitute the sources contributing knowledge of the techniques described.

LIST OF REFERENCES

1. Carlucci, F.C. III, "Improving the Acquisition Process," Memorandum for Secretaries for the Military Departments, Chairman of the Joint Chiefs of Staff, Under Secretaries of Defense, Assistant Secretaries of Defense, General Counsel, Assistants to the Secretary of Defense, the Deputy Secretary of Defense, Washington, D.C., April 30, 1981.

2. Lochry, R.R. Col, USAF, et. al., Final Report of the USAF Academy Risk Analysis Study Team, Deputy for Systems, Aeronautical Systems Division, Wright-Patterson AFB, OH., August 1971, (AD729 223).

WHAT IS RISK ASSESSMENT?



CHAPTER II

WHAT IS RISK ASSESSMENT?

A. GENERAL

The Introduction (Chapter I) referred to "formal, quantitative risk assessment" and stated that it was not identical to risk analysis. The questions remain, "What is risk assessment, and why are the modifiers 'formal' and 'quantitative' used?" This chapter is designed to answer those questions.

B. HOW IS IT FORMAL?

The reader may be familiar with assessments in which the author has used objectives "high", "medium", or "low" to express a general assessment of risk. There are undoubtedly circumstances under which such non-quantitative appraisals are appropriate, but the thrust of this handbook is to promote the language of probability and the use of its associated mathematics in risk analysis.

All program managers are conscious that acquisition programs typically involve a risk of failure to meet cost, schedule, or technical performance goals, and that their job is to reduce and control that risk. The risk assessment that this handbook describes differs from the top-level intuitive assessment exemplified by the "high", "medium", "low," statement in that it results in statements of risk that are quantified in the language of mathematical probability and that it commences with explicit examination of program elements at some specified level of detail. By examining the detailed elements of the program it is possible to find experts highly familiar with each element, experts who have experience in the field of which the program element is an example.

Most of the current systems analysis techniques are based on the concept that problems having large numbers of elements which

interrelate in complex manners can best be attacked by examining the elements in detail, determining individual relationships, and formulating a model from those building blocks to determine the behavior of the model. This requires formal analysis. The assumption is that most minds are less able to comprehend the whole of a problem than to comprehend all elements individually. Determining the cost, schedule and technical risks in an acquisition program is certainly a problem involving a large number of elements having complex interrelationships, thus the adjective "formal" applied to risk assessment signifies that the analytic technique will be used.

C. HOW IS IT QUANTITATIVE?

By now the reader should see that this handbook's risk assessment will be based on examination of program elements, using experts, in order to synthesize a model of some kind. The next characteristic of risk assessment to be addressed is the means of reducing the knowledge of the program elements experts to quantitative expressions of uncertainty.

The need for quantifying experts' inputs arises from the complexity of interrelationships between program elements. If the interrelationships were simple, implications might be easy to see, but since in most cases they are complex, it is advantageous to establish a mathematical description (model) so that magnitudes of the influences of their characteristics and interrelationships can be determined.

1. Subjective Probability

Before discussing mathematical probability methods for using experts' knowledge, it will be helpful to clarify what is meant by "risk". In this handbook "risk" is the term used to denote the probability of an event and its consequence.[1] When an

---

[1]In many disciplines "risk" and uncertainty are given distinct definitions, and program decisions under those definitions

event has a high probability of occurrence and an unimportant consequence, we say its risk is low. Similarly when its consequence is quite unpleasant but is probability of occurrence is very low, we also say its risk is low. On the other hand, the combination of a moderate probability of occurrence but importantly undesirable consequence will cause the risk to be termed "high." The concept of risk used in this handbook is that of the probability and consequence of not achieving some defined program goal (such as cost, schedule, or technical performance).

Acquisition programs can be considered "experiments" that have only indirectly related precedents, are extremely complex, and will be carried out only once. A mathematical person might say that this "experiment" is fundamentally different from the throwing of dice, an experiment which has clearly definable precedents, and therefore although mathematical probability is appropriate to dice throwing, it is not appropriate to acquisition programs. This argument is based on one viewpoint of the theory of probability. Another viewpoint holds that probability is a statement about lack of knowledge, and that when a person assigns a certain probability number to the occurrence of an event, he is saying that he cannot predict the event's outcome, but is willing to take some action (e.g., make a wager) so that his payoff and hazard are related by this probability number. This viewpoint has come to be called "subjective" probability, and although not all reputable statisticians accept the legitimacy of subjective probability, the validity of the theory has received a great amount of attention, and there is strong support in the statistical community for acceptance of the concept. Thus, the application of probabilistic assessments to the acquisition process has a strong rational basis. The interested

---

are decisions under uncertainty, not risk. Although the distinction is an important one, it is less confusing to avoid it here.

reader with a background in undergraduate probability theory will find a clear development of subjective probability in [1].

2. Statements of Probability

Most readers have been exposed to the familiar "bell-shaped" (or "normal") curve (such as that in Figure 2) used for such purposes as describing the chance that a bomb will fall to the left or right of a target by a given distance or that the product of a machine will differ from its specified size by a given amount. The kind of curve shown in Figure 2 is called a Probability Density Function (PDF) and is just one of the curve types described in this handbook.

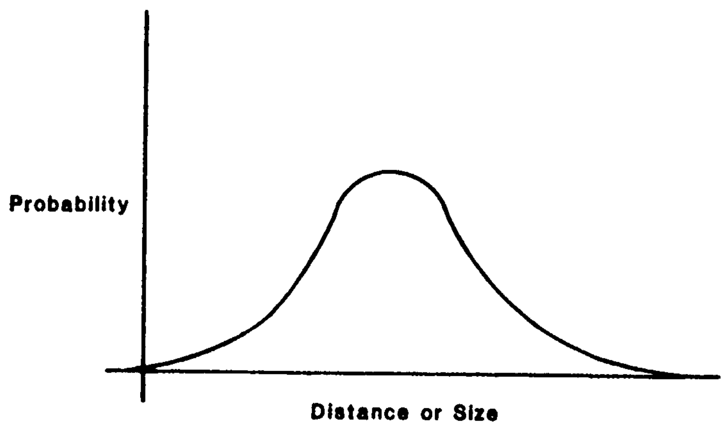


Figure 2
PROBABILITY DENSITY FUNCTION (PDF)

The other type is the Cumulative Distribution Function (CDF) as shown in Figure 3.

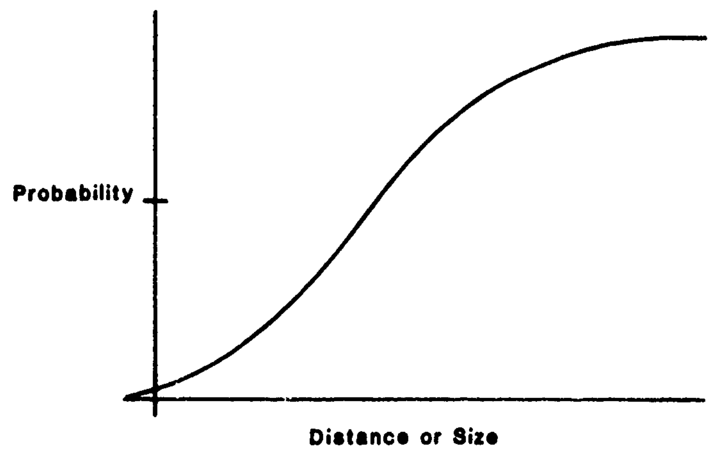


Figure 3

CUMULATIVE DISTRIBUTION FUNCTION (CDF)

Figures 2 and 3 are the types of curves used when the outcome of an experiment (bomb drop or part manufacture) can be a number anywhere within a range, not just at certain values (like throws of dice). For the latter type of experiment, the bar graph (histogram) like Figure 4 is used instead of the PDF.

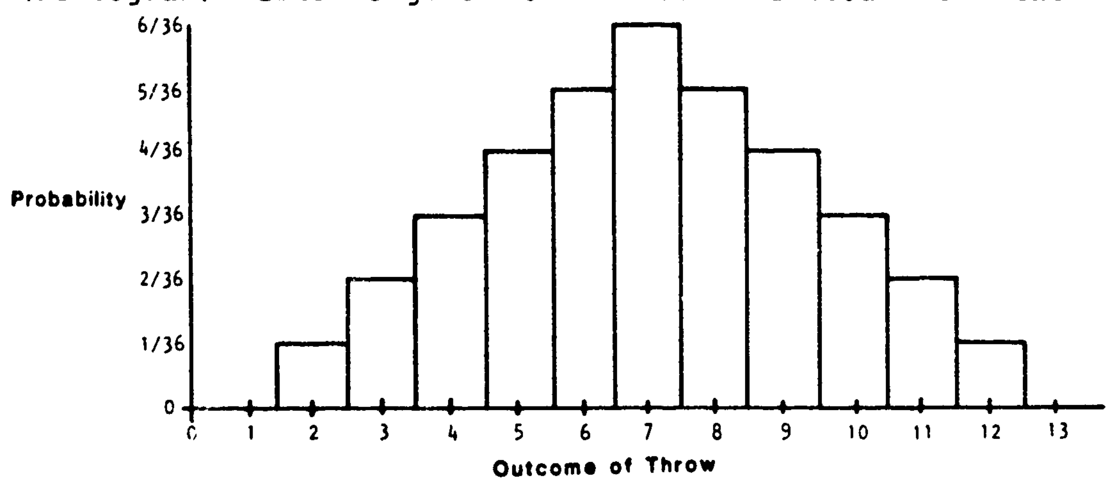


Figure 4

PROBABILITY MASS FUNCTION (PMF)

This bar graph is called a Probability Mass Function, (PMF), however since most of the ideas in this handbook can be conceived in terms of continuous curves (as represented by Figures 2 and 3), Probability Mass Functions will not be much discussed in this handbook.

Figure 5 is another example of a symmetric or normal PDF, representing, for example, the probability of final program cost.[2]

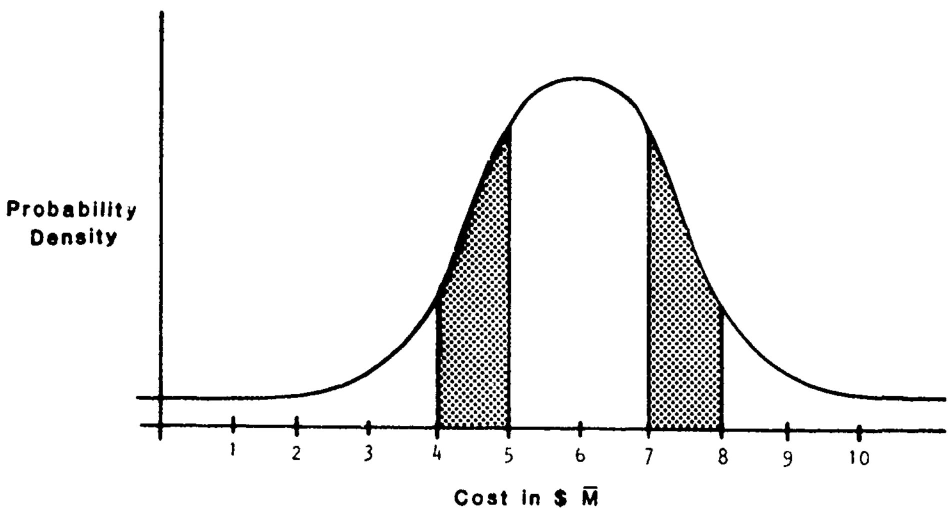


Figure 5
SYMMETRIC PDF FOR ELEMENT COST

In a PDF, the probability of an event occurring within a range of values is represented by the area under the curve within the range of interest. Therefore, since the two shaded areas in Figure 5 are equal, the curve indicates that the probability that the cost will be between 4 and 5 million is the same as the probability that it will be between 7 and 8 million.

In many of the concepts discussed in this handbook neither normal PDF's or other symmetric ones, such as represented by Figures 2 and 5, adequately represent the uncertain situations that exist in the defense acquisition environment. Two of the reasons for this follow. First, the normal curve assigns some (very small) probability to the occurence of an event, no matter

---

[2]In this section, for purposes of clarity, the uncertain variable will always be cost. Other variables of interest to

how far to the right or left it might lie. Since no program can have a negative cost outcome and because there generally is some dollar value (greater than zero) that represents the lowest possible program cost, the PDF's normally used in this environment touch the horizontal axis somewhere to the right of zero. An example of this is shown in Figure 6.

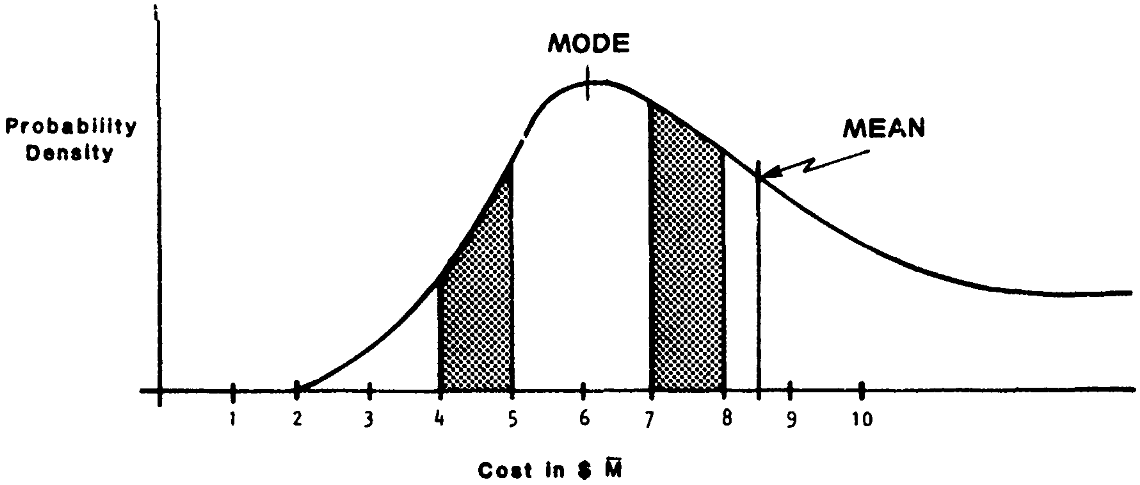


Figure 6
SKEWED PDF FOR ELEMENT COST

A second difference results from the fact that, just by the nature of the defense acquisition business, there is a higher probability of the ultimate cost outcome's exceeding the most likely value than there is of the outcome's being less than the most likely value. If this is the case, then the PDF cannot be symmetric and must take on a shape like that shown in Figure 6. It is said to be skewed right. Comparing Figure 5 to Figure 6, there is now a greater probability (larger shaded area) that the program cost will be between $7 and 8M than between $4 and 5M.

The amount that a PDF is skewed, like the amount of uncertainty it represents, can be expressed numerically, by a quantity

---

the program manager (e.g., schedule and technical performance) can be, and often are, assessed in the same way.

called "skewness". Absolute skewness is measured in various ways by different researchers, but one of the better known ways mesures it as the difference between the mean (average) and the mode (most likely) values. Dividing this difference by the standard deviation gives a relative measure of skewness, which can be positive or negative. A relative skewness measure of more than 1 (in absolute value) is considered to represent a highly skewed PDF. This would indicate that there is substantial uncertainty regarding the original cost estimates, and that there is a higher probabiltiy of costs exceeding the original estimate than of their falling short.

PDF's have certain other characteristics, some of them familiar, that a program manager should understand to appreciate what a risk assessment tells him, especially when he wishes to use the skewed types of PDF. The first of these is the mean (or "average" or "expected") value. This is the average value that will occur given a very large number of experiments. Another important characteristic is the mode, which is defined as the value where the probability curve is at a maximum. A symmetric PDF will have the mean and mode occurring at the same value, while a skewed PDF will have the mean removed from the mode toward the skewed side of the PDF, i.e., the side with the long "tail". Figure 6 locates the mean (the average cost--shown approximately--$8.5M) and the mode (the cost having the highest probability of occurrence at approximately $6M) for a skewed PDF.

Another characteristic of PDF's is the amount of uncertainty they express. This is shown graphically by the amount of spread in the curve. If the curve is low at its peak and broadly spread, a great deal of uncertainty is expressed; if it is high at its peak and narrow, little uncertainty is expressed. These qualities are measured by expressions called "standard deviation", (or standard error) and "coefficient of variation".

The CDF provides a different kind of information, a kind that is not as easy to visualize by using a PDF. As has been said, in

a PDF the probability of a range of occurences is represented as the area under the curve between two values bounding that range. Since it is hard to interpret such a representation, the CDF is commonly used. The CDF shows on its vertical axis the area under the PDF to the left of some particular value on the horizontal axis. Thus, as shown on the bottom of page II-11, the CDF allows such statements to be made as "there is a 40% chance that the cost of the program will be less than $5M." Of course, one can also state that "there is a 60% chance that the cost of the program will exceed $5M."

"Confidence" is another term often used in a statistical context. For example, a value (like cost) may be said to lie in a given 95% confidence interval, or there may be a 90% confidence that cost will be at or below some value. These kinds of statements can be made by using CDF's, as also shown on page II-11. The program manager can substitute "probability" for "confidence" in the latter statement, and he can translate the former to read "There is 95% probability that the cost of interest is contained within the stated interval."

To summarize the information contained in PDF's and CDF's, one can say that PDF's provide intuitive information about the uncertainty expressed, while CDF's provide more specific, but limited, quantification of some information not readily retrievable from PDF's. A PDF gives the limits expected to contain the uncertain value (the left and right end-points of the PDF). It shows the most likely value (the mode), and it may show the average value. It shows whether the value is considered more likely to exceed or fall short of the most likely value by whether it has positive (right-hand) skewness or negative (left-hand) skewness. Lastly, it provides a feel for the uncertainty expressed, by whether it is narrow and peaked (low uncertainty) or flat and wide (high uncertainty). Numerical measures of these visual signs are often provided for comparative purposes. The CDF allows statements to be made regarding the probability of the outcome being less than

(or exceeding) some particular value. CDF's also allow confidence statements to be made.

D. WHAT IS A (FORMAL, QUANTITATIVE) RISK ASSESSMENT?

A formal quantitative risk assessment is a mathematical means of integrating the detailed information possessed by numerous experts while preserving the experts' uncertainty and the complex relationships between the elements of information.[3]

The essence of the result is a statement of the probability of program outcomes (cost, schedule, technical performance, or combinations of them).[4]

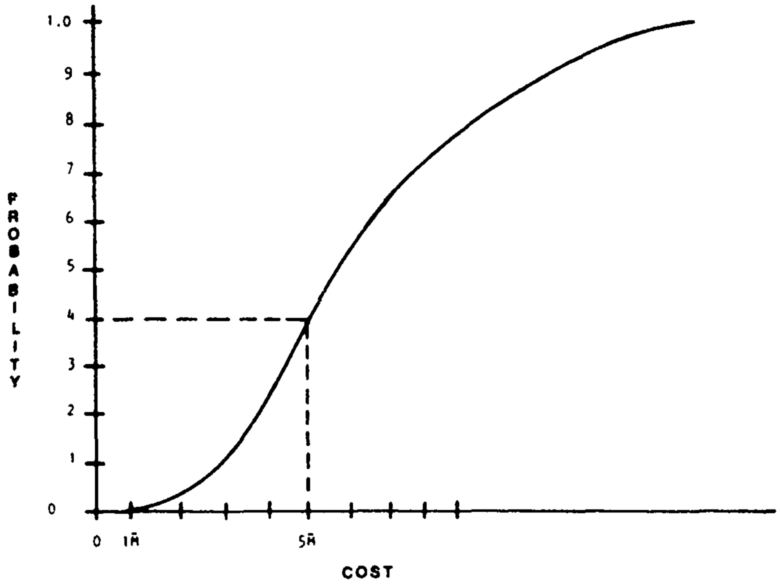
Although these statements have always been theoretically possible, practical difficulties are such that some simplifying assumptions are always required, and it is the type and amount of simplification that constitute the reasons for there being many risk assessment techniques. In most comprehensive types of risk

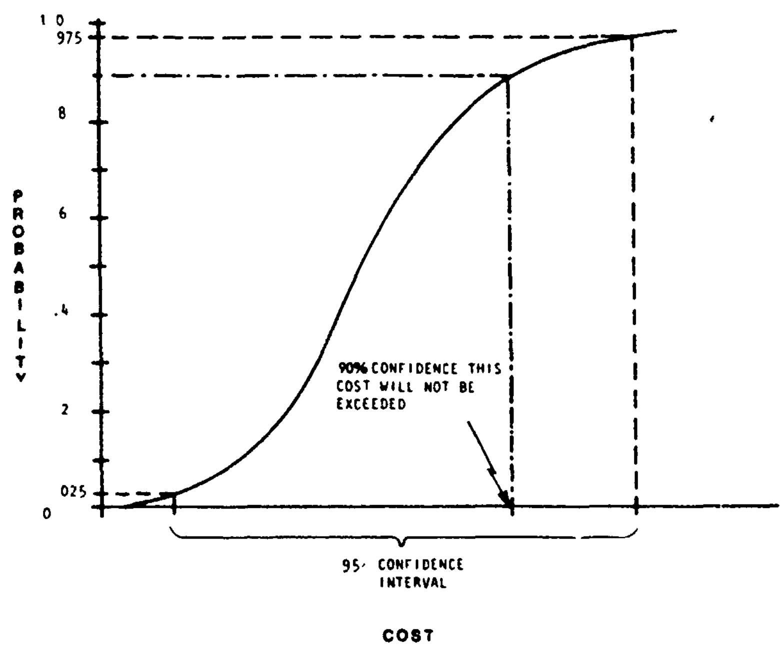
---

[3]The reader who is looking for an analysis that solves his problem of, say, cost risk, in the same way that an engineering method solves a design problem, should recall that no probability statement (read "risk assessment") can say what a program will cost; it only represents the aggregated opinions of the experts as to what it will probably cost. Also, there is no proof of correctness in the final outcome's lying closer to the value given by the risk analysis at some percentage level (typically a high one) than to the original point estimate. All that can be said about the point estimate is not that it was wrong, but that as an opinion of risk it failed to represent the thinking of the experts very well. As far as the outcome goes, it only represents one "throw of the dice" in a (never-to-be-undertaken) infinite series of throws, the record of which will, if the experts are right, be closer and closer to the PDF resulting from the risk assessment. It is no more a proof of correctness than is any other value. Seven may be the most likely outcome of a throw of a fair pair of dice, but the actual occurrence of a seven does not justify the prediction of a seven on any single throw, although it may justify a wager on the occurrence of the seven.

[4]A PDF or CDF relating to two or more outcomes and their occurrence together is called a "joint" PDF or CDF. Since three dimensions are involved, it is usually not graphed.

assessment, the statement of program outcome probability will be made in the form of a PDF, a CDF, and the numerical measures described above. In other types of less depth, the results are restricted amounts of the same kinds of information or are simply determinations of budget levels needed to accommodate risk to some degree.



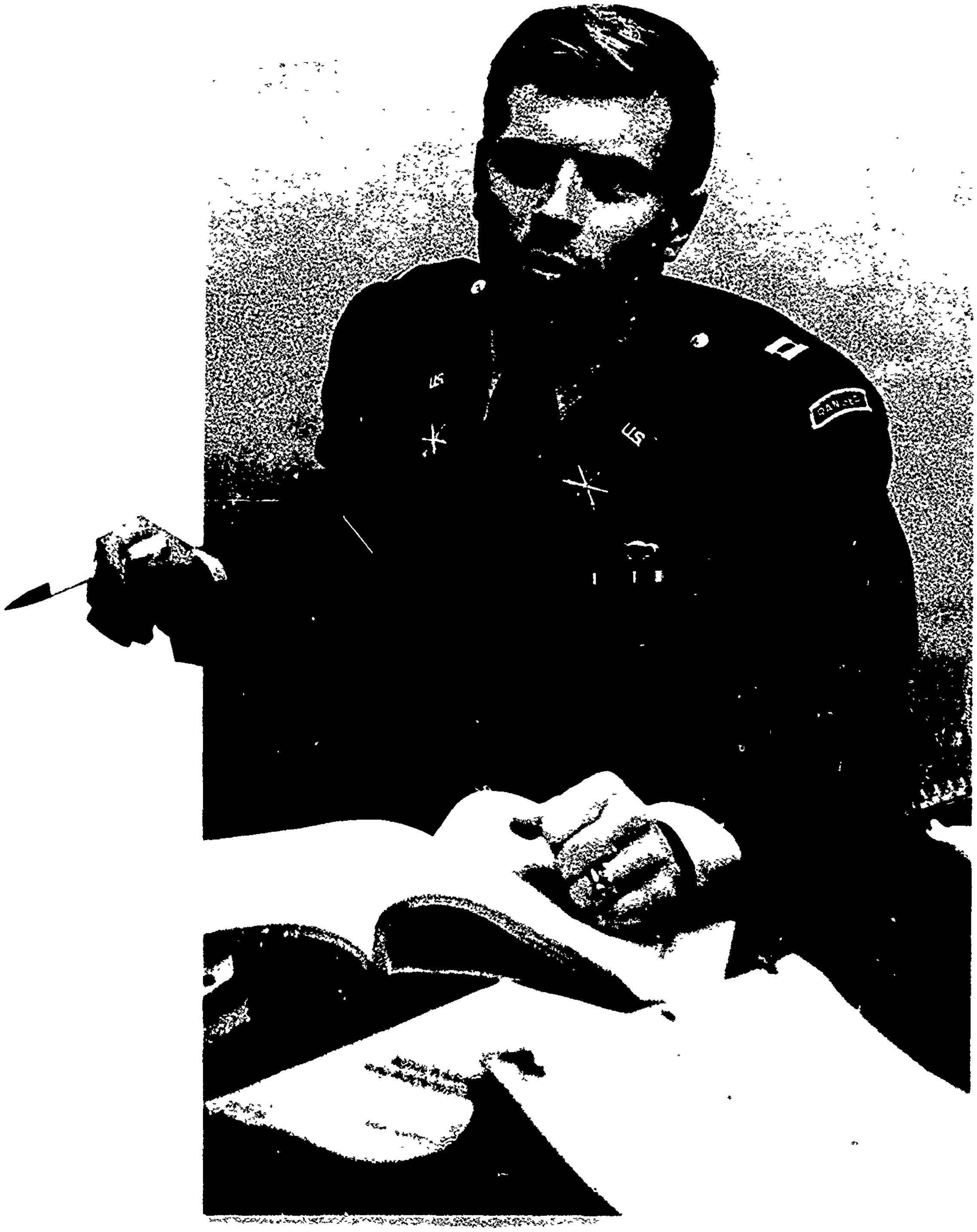


LIST OF REFERENCES

1. Raiffa, H., Decision Analysis: Introductory Lectures on Choices Under Uncertainty, Addison-Wesley, 1968, (#).

(#) No AD/LD number for this document.

WHY DO A RISK ASSESSMENT?



CHAPTER III

WHY CONSIDER RISK ASSESSMENT?

A. GENERAL

The problem of acquisition program cost growth seems ever-present. As a consequence, OSD and military services have initiated a number of management programs over the past three decades in efforts to control cost growth and to reduce costs to more acceptable levels. The most significant of the recent programs is the Acquisition Improvement Program which started with the Carlucci memorandum referenced in Chapter I. Initiative Number 11, which provides the stimulus for this handbook, may seem to some program managers to be telling them to do what they consider to be the primary function they currently perform, the management of risk reduction. "Besides," they might say, "my cost estimates are based on the latest cost estimating techniques using data from the most similar known programs, and contain a reserve for unknowns wherever that seems reasonable." They feel that there can be no substitute for intimate program knowledge at the top management level, and that their understanding of program risk can only derive from immersion in the program's day-to-day financial, engineering, and scheduling problems.

The business of program office personnel is certainly the continuing analysis and modification of plans, designs, and cost estimates, and the intensity of this effort is not lessened by employing more formalized methods of risk assessment than the somewhat intuitive approaches in customary use. Indeed, this intense study of the program is a prerequisite for the use of more formalized methods and in fact is the first step in a quantitative risk assessment.

What, then, does formal quantitative risk assessment provide that the customary "problem immersion" approach does not? The immediately discernable benefit is the one common to all for-

malized analysis techniques; i.e., provision of an accepted structure of logic, permitting improved communication and evaluation. A formalized logical structure enhances identification of points of agreement and thus promotes objectivity.

The next most obvious benefit, derived from quantification, is also again an improved communication, this time in identifying the relative importance of assumptions and program elements and the degree of any existing disagreements. Quantification futhermore permits investigation of the sensitivity of assessment conclusions to the identified disagreements. A final general advantage of formalized quantitative risk assessment over unstructured approaches is its capability to utilize expert opinion directly and in a clearly identifiable and measurable way. The limitations of the human mind are such that unstructured assessments of risk are unlikely to account for more than six or eight separate considerations, and the amount of modification to, or weighting of, expert opinion is not likely to be discernable, thus, basis for objective discussion may fail to exist.

A program manager finds himself drawn in two directions regarding budgets. If he fails to obtain sufficient funds on time, he risks either program failure or cost growth due to program stretches or inefficiencies. If he requests excessive funds he risks program cancellation for non-affordability. A formalized quantitative risk assessment permits him to determine otherwise unknown implications of funding levels, to communicate those implications credibly to reviewing authorities, and thus to enhance his chance for program success.

B. COST VS. BENEFIT

1. Costs.

If cost can be considered as the expenditure of resources, a program manager will be concerned with at least four "costs" of conducting a risk assessment; i.e., expenditure of funds, time, manpower, and management attention.

The funds required to conduct a risk assessment can vary from small to substantial amounts, although compared to the costs avoided as a result of a risk assessment it is probably negligible. Nevertheless the program manager will be concerned about even moderate expenditures, for example, early in a program when overall cash flow is low.

Time can be considered a "cost" in that delay pending completion of a risk assessment can forestall accomplishment of other program activities. Risk assessment techniques vary in the time required from a few hours to a number of months, but the selection of techniques and their integration and program activities can be accomplished so as to minimize schedule impact.

Manpower as a "cost" includes the man-months required of subordinate program office personnel or of support office analysts. These "costs" may vary from a few man-hours to more than six man-months. Again, techniques are available which allow selection of a method appropriate to the resources of the program office.

A final "cost" is that of management attention. It has been found that for a program manager to derive significant decision-making benefit from a risk assessment, he must be willing to commit substantial amounts of personal attention to the assessment. He must understand and approve the concept and approve the assumptions of any model developed by analysts. He must review the analysts' progress and findings, keeping them updated on program changes. More detailed discussions and estimates of these "costs" can be found in Chapter V.

2. Benefits

The expenditure of the resources cited above yields direct and indirect benefits, the direct being the explicit output of the risk assessment, and the indirect being by-products of the assessment process.

Direct benefits include credible budgets with explicit (although probabilistic) consequences. Since in the case of detailed analyses, PDF's and CDF's can be examined, a program manager can see the amount of risk he is facing (by such measures as standard deviation and coefficient of variation) and whether his program is more likely to underrun or overrun (by the sign of the skewness) and the relative magnitude of the likelihood (by the magnitude of skewness). He can also see the most likely cost (by the magnitude of skewness -- the mode and the probability that any funding level will be sufficient (the probability associated with that level on the CDF), besides the probability that costs will be within any specified limits (the CDF probability of the lower subtracted from that of the higher). Needless to say, material in support of credible estimates will aid in this justification of costs used in service POMs, DOD budget hearings, and Congressional reviews.

An assessment of schedule risk can provide direct evaluation of alternative schedules, including not only their probabilities of success, but also, their probable funding requirements.

Examination of the inputs to risk assessments identifies the high risk program elements and thus points out the areas where risk management should be focused.

One indirect benefit which is a significant by-product of a detailed risk assessment is the improvement of program definition resulting from the methodological requirement to specify all program activities and their dependency on other elements. Not only is program definition improved but all members of the program team develop improved understandings of the total program and their places within it.

A second indirect benefit is the enhanced problem solving insight provided by knowledge of how risks and performances can vary when conditions and assumptions change.

The list of specific decision categories supportable by application of quantitative risk assessment techniques (some of which have not been mentioned previously) include:

- Program control
- Major planning decisions
- Acquisition strategy selection
- Technical alternative selection
- Contract structuring
- Source selection

Discussion of how quantitative risk assessment supports decisions of these types can be found in Chapter V and Appendix D. Appendix L summarizes in chart form the products of various assessment methods and matches them against decision categories to which they can be applied.

WHAT TECHNIQUES ARE AVAILABLE?

CHAPTER IV

METHODS OVERVIEW

A. GENERAL.

Although researchers continue to develop new risk assessment techniques and applications, this chapter will summarily describe only the seven quantitative techniques in predominant current use. The quantitative techniques to be described are:

- Network analysis
- The method of moments
- Decision analysis
- WBS simulation
- Graphics
- Estimating relationships
- Risk factors

Although there are applications mixing the techniques, these seven constitute the majority of those potentially applicable to ongoing (rather than conceptual) programs.

In addition to the quantitative techniques, there are two non-quantitative methods which in this handbook will be called "structured qualitative" and "engineering analysis". The latter is this handbook's term for the unstructured "problem-immersion" approach discussed in Chapter III; the former is a more structured derivative. These two are mentioned because "engineering analysis" is the approach in predominant military acquisition program use and the "structured qualitative" method (exemplified by [5]) represents an upgrade of the "engineering analysis" method. The "structured qualitative" approach improves on "engineering analysis" by providing explicit criteria for judgment of risk, by adopting a logical structure, and by documenting its rationale.

The seven quantitative risk assessment methods which follow are described briefly in the following sections, and discussed in greater detail in Appendix F.

B. NETWORK METHODS

1. General

Most managers today are familiar with the concept of modeling an acquisition program as a network, such as that in Figure 7, made popular by the Polaris submarine project and termed the Program Evaluation and Review Technique (PERT).

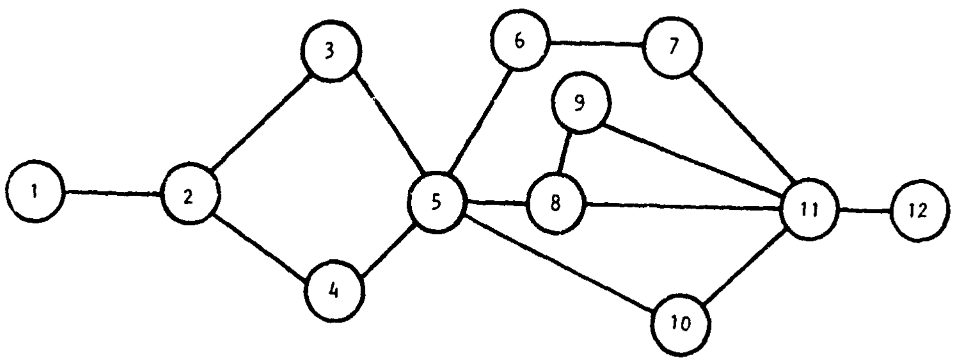


Figure 7

PROGRAM REPRESENTED AS A NETWORK

In such a network, each circle represents a decision point or milestone, and each line represents an activity that must be finished to advance the program, that consumes resources, or that takes time. In the PERT approach the objectives were to manage schedule risk by establishing the shortest development schedules, to monitor and project progress, and to fund or apply necessary resources for maintaining the schedule. Successors to PERT

included PERT/COST in which the minimum cost path through the network was estimated, and the project was managed to minimum cost. PERT models lacked the capability to include probability information on the cost and/or schedule, however current network models can use computers to arrive at probability statements incorporating evaluations of cost, time, or performance level values by means of a technique called simulation.

Typically, the analysis in PERT models was based on average, and sometimes extreme, values of activity duration. In current techniques, the network is defined, and the activity probabilities of cost or schedule are described. Then, by using computers to simulate a large number of program completions in which events occur according to their probabilities, the probabilities are evaluated for the network as a whole. Subsequently, probability expressions such as confidence levels, etc. (as described in Chapter II) can be made. Thus the subtle and complex interrelationships of the hundreds of activities required to complete a program can contribute to the same degree they would in the actual program, assuming all activities truly behave as expected. The fact that the activities may not behave exactly as expected, that is, that no model is perfect, is irrelevant. The decisions must be made and must be based on the best information available at the current time. The model represents that best available information, or the analyst must change the model.

2. Inputs/Outputs

a. Inputs

Establishment of a network model requires definition of each program activity, its beginning, its end, its possible predecessors, and its possible successors, at some specified level of detail. The last phrase signifies that activities themselves can almost always be restructured into more detailed activity networks. Part of the art of network modeling, a matter the

program manager may wish to review, is the level of detail to use, since increased detail increases complexity, cost, time, and manpower requirements. The inputs described so far say nothing about probability. Each activity must also be described in terms of probability, with the probabilities relating to cost, schedule, manpower, technical level of achievement, or some combination. Also, when it is not certain which activities can occur at a decision point, it is necessary to input probabilities of those activities. Some computer programs limit the characteristics that can be described by probabilities, while some are virtually unlimited but require more computer resources (see Chapter V).

b. Outputs

Network model outputs typically include PDF's, CDF's, and the statistical measures described in Chapter II for the cost or schedule of the entire program or specified parts of it. Other outputs include lists of the activities or groups of activities that have caused program difficulty, in order of their frequency of causing it. This is called "criticality," a term derived from the PERT term "critical path". A PERT critical path is the sequence of activities in a network having the longest duration or highest cost.

3. Resource Requirements

Since most network risk assessments accomplished in the DOD are carried out by functional support offices, risk assessment dollar costs should be estimated from manpower requirements. A comprehensive network analysis for a major program may require definition of between 200 and 1000 activities and require 2 to 6 man-months of GS-12 to GS-14 analyst effort for gathering experts' PDF's and for building the network. The analysts must obtain lists of program activities and information on the sequence of activities from Program Management Office (PMO) per-

sonnel and from the members of the organizations supporting the PMO. Obtaining this information consumes more time and requires more re-checking than might seem necessary. This is because the program plan is usually under continual revision and definition, and the support personnel themselves do not fully understand the program activity interdependencies.

Although the difficulty and time required for network definition is a problem, the effort of constructing a consistent and acceptable network model forces the responsible participants to plan more effectively and to understand how their own segments of the program fit into the whole. Program managers have indicated that this benefit can justify all the effort for accomplishment of a formal network risk assessment.

Having recognized the difficulties associated with developing networks for particular acquisition programs, some Army commands (at least MERADCOM and CECOM) have generated "dictionaries" of the activities typically required during the life cycle of a program. These "dictionaries" provide descriptions of the activities, typical durations, and interrelationships with other activities. The activity descriptions, along with a sample network, provide an excellent starting point for PMO personnel and analysts attempting to develop a program network. The existing "dictionaries" are somewhat tailored as they, of course, reflect service and command-peculiar requirements and apply to the types of systems procured by the author commands. They are mentioned here as suggestions of what would be possible in other commands.

4. Applications

Network risk assessment models have been used throughout the Army in support of In Process Review (IPR), Army Systems Acquisition Review Council (ASARC), and Defense Systems Acquisition Review Council (DSARC) program reviews. Navy program offices of NAVSEA have obtained contractor support for network

based risk assessments for appraisal and control of both major acquisition programs and overhaul programs. No examples of USAF use of network risk assessment techniques were found during preparation of this handbook.

C. Decision Analysis Methods

1. General

Decision analysis is the examination of decisions by breaking them into the sequences of supporting decisions and the resulting uncertain occurrences. Usually, these sequences are represented as decision "trees" such as that in Figure 8. Interesting and extensive treatment of the subject may be found in [16].

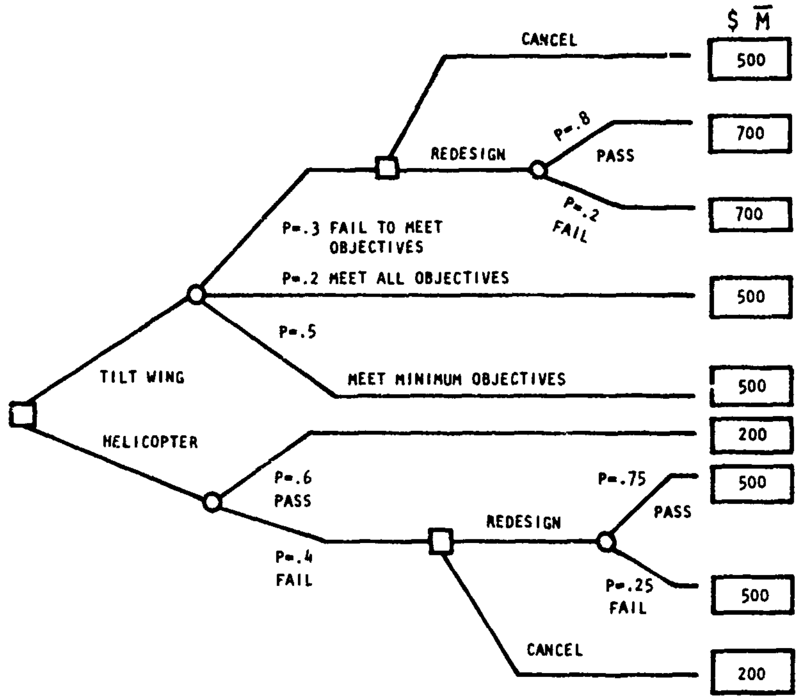


FIGURE 8

DECISION TREE

The first, left-hand square in Figure 8 represents an aircraft conceptual decision that can be made in either of two

ways; i.e., select a tilt-wing design or a helicopter. The circles that follow represent test programs that have, on the top branch, three possible outcomes or, on the bottom branch, two possible outcomes. The likelihood of each of these outcomes is shown on the appropriate branch (e.g., P=.3 indicates a probability of 3 in 10 that the tilt wing design will fail to meet test objectives). The next set of squares represent decisions that might have to be made after each outcome. Some of these decisions are followed by new tests. In the boxes on the right-hand side of the tree, the funding consequences of each of the branches are shown.

The complication of managing a large and unwieldly decision tree can be avoided by using a simplified approach, called Probabilistic Event Analysis (PEA) and described in [20]. While the simplified method provides for determining which activities and milestones for major WBS elements contribute to cost, as though milestones were decisions on a decision tree, the tree does not have to be drawn, but the logic is the same. The analyst defines the problems which he feels may effect the program cost or schedule and assesses the likelihoods of their occurrence. The analyst continues by obtaining assessments of the effect of each type of problem on the cost or schedule of the relevant function or milestone. From the probabilities and the magnitude of effects, an "expected value" of cost increment for each effort can be calculated.

A more elaborate method is described in [8], which first orients the assessment around a specific program sequence that allows the analyst to define the program as in a decision flow diagram (decision tree). In this method, time and cost effects of identified problems are estimated as in the former method. A series of simple, but tedious and voluminous, probability calculations allow the analyst to establish cost and schedule probability distributions for each phase. These distributions are then combined by using them as inputs, not to a pencil and paper calculation, but to a simulation on a computer.

Although the mathematics underlying these decision tree approaches are undemanding and the network simulation can be much simpler than those discussed under network methods, analyzing the relationships is not simple, and any computer use requires a degree of sophistication to carry out the programming. It is particularly difficult to ensure comprehensive identification of problems and time/cost effects.

2. Input/Output

a. Inputs

Decision analysis methods require definition of the program decisions to be made, again, as in any model, at some convenient level of detail. These may include many of the milestones that are inputs to a network analysis, but in the decision analysis model, the emphasis is on the points where decisions are made, not on the sequencing of activities. Rather than defining PDF's for activities, usually a specific small number of problem occurrences is defined for any point in the decision logic where chance enters in, and the subject matter experts are polled to obtain probability estimates for all possible occurrences, the problems that could ensue, their cost impacts, and their probabilities. Thus, the inputs for this method are:

DECISIONS

Potential Problems	Probability of Occurrence	Possible Resolutions	Probability of Success	Cost Impact

In the method of [8], not only are the problems, their probabilities and their cost (or schedule) impacts obtained, but each problem's resolutions, resolution(s) probabilities of success, and resolution cost (or schedule) impacts are also used.

b. Outputs

The cost oriented Probabilistic Event Analysis output is a reserve to be added to the baseline budget established without

consideration of the problems subsequently addressed in the PEA. Nothing similar to a PDF is generated and no statement can be made relative to the probability of exceeding the new budget.

The method described in [8] provides "joint" probability graphs showing program probability of success at given probabilities of needing stated levels of funding (or time).

3. Resource Requirements

Probabilistic Event Analysis was developed to demand less time and analytical skill than network methods. As with other methods, the most time-consuming part of a PEA is probably obtaining comprehensive determination of critical occurrences, their probabilities and their impacts, in other words, data collection. For a program for which the plans have been stabilized, a GS-12 or -13 might require no more than a few days to complete a PEA.

The type of decision analysis described in [8] will probably require an analyst of greater knowledge and skill than a PEA and perhaps than even a network assessment. Some computer programming will be required, data collection is likely to be more comprehensive and demanding, and interpretation of results may require more sophistication. A typical team (that for [15]) consisted of a GS-15 analyst with two lower grade (GS-13/14) team members, and the assessment consumed about 4 months.

4. Applications

No examples of application of the PEA method were found in preparation of this handbook. The method described in [8] has been used at the U.S. Army Air Mobility R&D Laboratory, Ames Research Center, Moffet Field, CA., for a Cobra Armament Program, and for the XV-15 program. No USN or USAF applications of decision analysis applications to risk assessment were found during handbook preparation.

D. THE METHOD OF MOMENTS

1. General

In network risk assessment methods, the program activities are related according to their sequencing, and the combined effects of their probabilities are determined by simulation. In the method-of-moments (developed in [13]) no network sequence relations are defined, and the combined effects of program element probabilities are determined by mathematics instead of simulation. Method-of-moments assessments concern themselves with cost risk and proceed from a framework of costs like a Work Breakdown Structure [14], sometimes called a cost breakdown. Each of the cost elements (not activities, as was the network case) has some probability "statement" (PDF) associated with it. PDF's may be humped and symmetric, indicating that cost is equally as likely to be above as below the most likely; or humped but skewed, indicating a greater likelihood that cost will be on one side of the most likely value than the other. However they are shaped, they combine to produce some total program cost PDF.

As was stated in paragraph D of Chapter II, simplifying assumptions are required in formulation of any mathematical description (model). For example, one of the simplifications used in network models is selecting the level of detail. In the method-of-moments, a major simplification used is that of selecting a total combined PDF, which is assumed to be a type possible to calculate by this technique. While this is a major assumption, it does not render the technique worthless. Typically the assumed PDF exhibits right-hand (positive) skewness, is assumed to have some unspecified lowest possible value (hit the axis on the left), and may or may not have a highest possible unspecified value (hit the axis on the right). Typically, a network simulation cost risk analysis does not produce one of these "well-behaved" PDF's, and some analysts would say that shows that assuming a well-behaved PDF type makes the

method-of-moments valueless. It must be remembered, however, that many less-than-major programs are unable to command the resources for a network risk assessment, so a method-of-moments assessment, while less than perfect, can provide otherwise unavailable insights.

The method's name comes from the fact that the "moments" of the cost element PDF's are used to form the "moments" of the combined PDF of total cost. Some of the better known moments are the mean and the variance (the standard deviation squared), which describe respectively the "center of gravity" of the distribution and the spread of costs around the mean. There are other moments, such as "skewness", which describes the distribution's assymetry, and others more difficult to visualize. For more on moments themselves, reference should be made to a probability theory or statistical theory textbook.

A PDF is mathematically described by a formula having certain constants (parameters), the values of which establish the PDF's shape. The method-of-moments correctly gives the parameters that determine where the PDF starts, where it peaks, how much it spreads, how quickly it comes down off the peak, and where it ends. The procedures are discussed in more detail in Chapter V.

In theory, even without the method-of-moments, one could compute a resultant PDF describing the multiplication and addition of a number of uncertain element costs. As a practical matter, though, it has been considered heretofore impossible, even when using large computers, which is why analysts have usually had to resort to simulation. Given the method-of-moments, analysts and managers can now make inferences about program cost probabilities with substantially less effort than a network analysis might require. For example, it is possible to carry out the method-of-moments calculations on a hand calculator, although appropriate programs would have to be written to make it convenient.

2. Input/Output

a. Input

As stated above, the framework for a method-of-moments analysis is the program cost breakdown rather than a description of program activities. The cost element probabilities are described using PDF's just as the activities in the network method are. Because some of the cost elements may be costs for exactly the same activities as are described in network assessments, some of the same PDF's may appear, but the overall set of inputs will probably be quite different since in the method-of-moments the effect of schedule cannot be treated independently.

The analyst will perform calculations using information taken from the input PDF's supplied by subject matter experts. This allows him to calculate the specific shape of the assumed PDF type representing the combination of cost elements into a total cost.

b. Outputs

Method-of-moments assessments directly produce the numerical measures associated with PDF's that were described in Chapter II; i.e., mean, standard deviation, and skewness. From these, and using the analyst-assumed PDF type, the specific PDF and its CDF can be drawn. This permits the making of all the same kinds of statements (except those concerning criticality) as can be made following a network risk assessment that addresses cost only.

3. Resource Requirements

The avoidance of the need for computers means that the method-of-moments could be carried out by a single person (a GS-13 analyst, with some reading and study). As with the network method, a large part of his time would be consumed with obtaining

experts' PDF's, but definition of a cost breakdown may take much less time than definition of a detailed program network. For the program of less-than-major size, for which this method seems best suited, assuming a cost breakdown has already been constructed, the computations might require less than a week of effort. If pre-written programmable hand calculator programs can be obtained, only a few hours will be needed to organize data, perform calculations and document numerical output. The reader should note that obtaining experts' PDF's can require an hour or more per expert, thus, the total time saved is not in the same proportion as that saved in computation. In other words, cutting computation time in half does not cut assessment time in half if data collection time is the same.

4. Applications

No examples of DOD method-of-moments application were found during preparation of this handbook.

E. WBS Simulation Methods

1. General

WBS (or cost breakdown) simulation methods perform the same function and use the same concepts as the method-of-moments. As with the method-of-moments, more than one variant exists and three are described in [1], [9] amd [17]. The difference between the method-of-moments and WBS simulation lies in the fact that the WBS simulation requires a computer and the method-of-moments does not. The computer is used to generate the PDF for system total cost by performing large number of simulation runs. These runs provide sums of elements costs that are generated from the input cost element PDF's. Specific computer programs that have been used with this method are described in [1], [9] and [16].

2. Input/Output

a. Input

Inputs are the same as for the method-of-moments, i.e., PDFs are obtained for each cost element by consulting experts in those element categories.

b. Output

Outputs are the same as for the method-of-moments.

3. Resource/Requirements

Skill requirements and costs for this method may be slightly greater than for method-of-moments assessments since use of a computer is required. Otherwise, resource requirements should be nearly equal.

4. Application

The WBS simulation method is used in the Office of the Chief of Naval Operations. A variant of the method is used in the Directorate of Cost Analysis, Deputy for Comptroller, Armament Division, Eglin AFB, FL. A straightforward application is used in the Directorate of Cost and Management Analysis, Comptroller, Headquarters Air Force Systems Command, Andrews AFB, D.C.

F. THE GRAPHIC METHOD

1. General

The graphic method uses graphs of program cost element CDF's and some simple algebra to express program cost uncertainties and to combine the element CDF's to obtain the resultant overall cost CDF. That graph allows the same statements to be made about probabilities of cost as does any CDF.[1]

---

[1]Another graphic method uses graphs to determine the moments to be used in a method-of-moments approach. It is discussed

This method, which is described in [10] and is discussed in more detail in Appendix F, describes the uncertainty of Work Breakdown Structure element costs in terms of normal (bell-shaped) CDF segments and from them finds the CDF of total cost using normal curves. In other words, it performs the same function as the method-of-moments and WBS simulation but makes use of different simplifying assumptions. It also has a more restricted result. The simplifying assumption is that CDF's can be approximated by joining parts of normal CDF's. The assumption greatly weakens the validity of the method but may be acceptable for a speedy approximate solution.

A special tool needed for this method is "normal probability paper"--a special graph paper whose vertical lines are spaced in accordance with the slope of a CDF for a normal (bell-shaped) PDF. Straight lines on this paper have the values that a normal CDF curve has on standard graph paper. A good office supply source should have normal probability paper.

In this method the analyst determines from experts the cost estimates for WBS elements at 10 percent, 50 percent, and 90 percent confidence levels. These estimates are the expert's beliefs that there are 10 percent, 50 percent, and 90 percent chances that each WBS element will end up costing less than or the same as the corresponding cost.

Having determined the three values for each cost element, the analyst next plots the values as points on a separate piece of the normal probability paper for each cost element as in Figure 9.

---

in [19], but will not be covered further here.

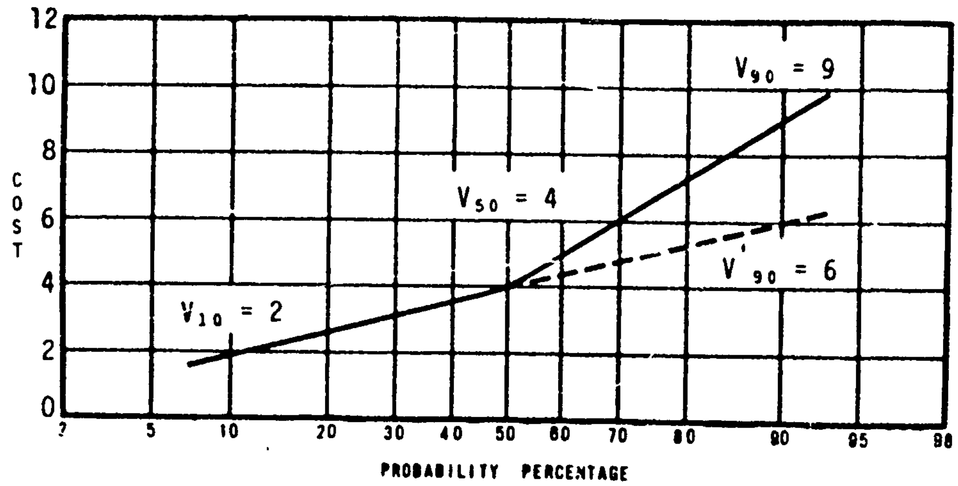


Figure 9
COST ELEMENT UNCERTAINTY

For example, if costs are in millions on Figure 9, the plot shows an experts' opinion that there is a 10 percent chance of costs less than about 2 million (V_{10}), a 50 percent chance of costs less than 4 million (V_{50}) and a 90 percent chance of costs less than 9 million (V_{90}) for a given cost element.

If V_{90} had been at the point labeled V'_{90} a straight line would have resulted, and the CDF described would have been that of a normal (bell-shaped) probability. Instead, a CDF is produced that represents a PDF like the darkened lines in Figure 10.

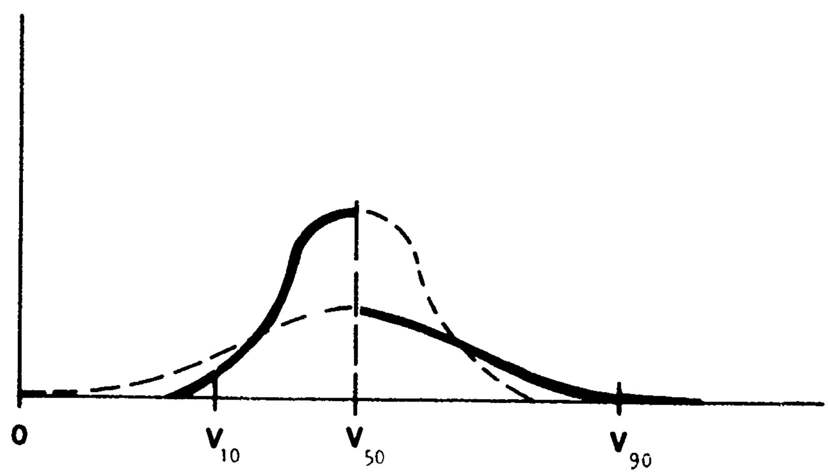


Figure 10
EQUIVALENT PDF FOR GRAPHIC METHOD

Even though that PDF seems not to fit most people's concepts of how probability should behave, it has two advantages. The first is ease of manipulation. The second is that it exhibits skewness, implying costs are more likely to overrun than underrun which seems generally more realistic.

With V_{10}, V_{50}, and V_{90} from each cost element graph, and with some factors determined from graph values and a table given in Appendix F, the element cost CDF's can be combined and the CDF graph of the overall system cost can be drawn.

2. Input/Output

a. Input

Input to this method is of the same type as that required for method-of-moments and WBS simulation, namely PDF's representing subject matter experts estimates of cost element probability. These PDF's, however, are approximations constructed from the experts' statements regarding costs at three levels of probability, one of which must be 50 percent, one less than 50 percent, and one more than 50 percent. Of course, a cost breakdown is also required.

b. Output

The output for this method is restricted in the same way that decision analysis methods are limited; the output is solely a CDF. No numerical and not much intuitive information is supplied about uncertainty (since there is no standard deviation information) and skewness. What is provided is an estimate of the most likely cost (that at the 50 percent level), and the probability of underrunning (or overrunning) any selected cost.

3. Resource Requirements

Resource requirements for this method, including skill requirements, should be on the same order as those for an equiva-

lent method-of-moments assessment. (It is worth repeating that the more arguable assumptions in this method suggest that it provides lower quality results).

4. Applications

No examples of DOD uses of this method were found during preparation of this handbook.

G. THE ESTIMATING RELATIONSHIP METHOD

1. General

The estimating relationship, described in [3] and Appendix F, allows a program manager to evaluate his program and enter a curve like that in Figure 11 with a contract rating, explained below, in order to determine a percentage management reserve.

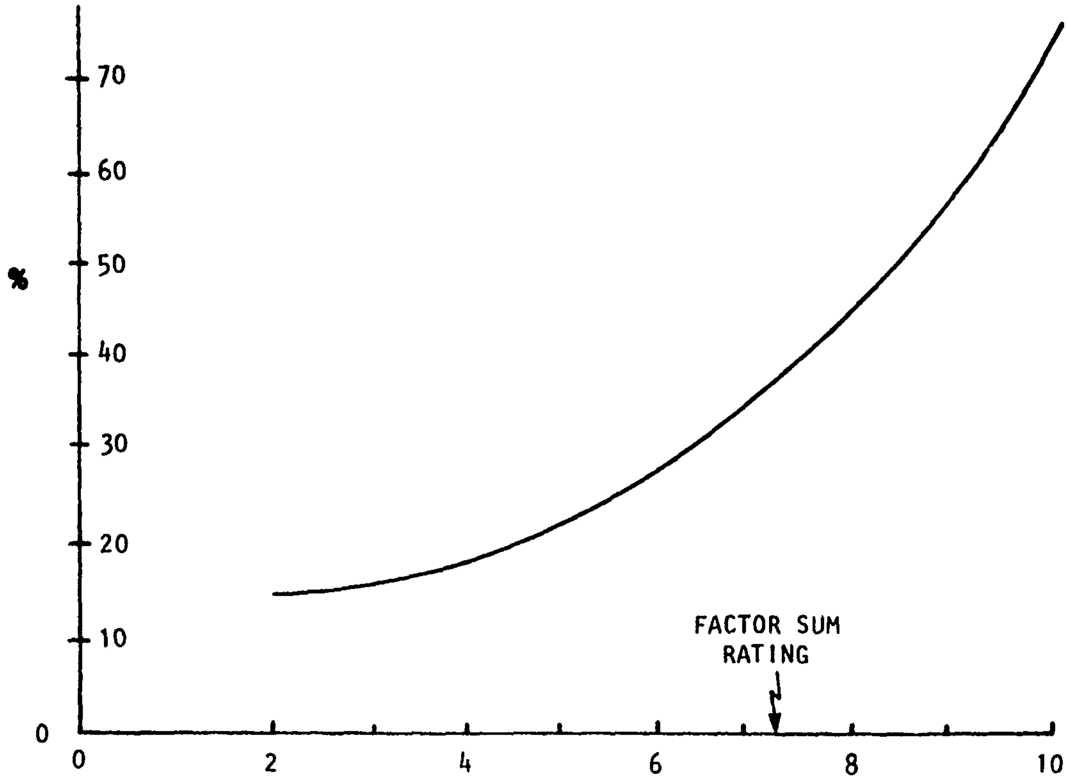


Figure 11

ESTIMATING RELATIONSHIP FOR MANAGEMENT RESERVE

In this method, management reserve represents the amount of funding, above that determined by cost analysis alone, that it is desirable to allocate to a contract to provide for technical risk.[2] The management reserve is expressed as a percentage of the baseline estimate. The method is called an estimating relationship method because it uses some of the same techniques as the Cost Estimating Relationships (CER's) used in parametric cost estimating.

Cost Estimating Relationships are the result of mathematical methods that determine a relationship between cost and one or more measurable system characteristic such as weight, speed, or volume. The method makes use of a statistical technique called regression analysis to develop an equation to fit a body of data. The data consist of known costs of similar systems, along with their associated sets of data for system characteristics.

The successful use of regression analysis for CER's has led to an attempt to use the same approach for estimating budget requirements to account for technical risk. The application of this approach makes use of categorical definitions for four "factors" derived from an examination of a number of contracts. The "factors", engineering complexity, degree of system definitization, contractor proficiency/experience, and multiple users, are qualities having different levels by which they can be described.

By using descriptions of historical contracts and the amounts of management reserve they used, a formula was contrived which is the basis of the curve in Figure 11. This curve should only be used for systems similar to those from which the data resulted.

---

[2]Note that this method has been developed and used for contracts, not programs.

To use the method, a contract is described by program management personnel and rated relative to the factor levels. The factor ratings are summed and the result is entered into the Figure 11 curve on the horizontal axis to determine an appropriate management reserve on the vertical axis.

2. Input/Output

a. Input

The inputs to the model, the equation of the curve for Figure 11, are the judgemental numbers characterizing the possible contract factor levels.

b. Output

The estimating relationship method provides a percentage figure to be applied to estimated baseline contract cost in determining the amount to supplement the contract for Management Reserve and Engineering Change Order Allowance.

3. Resource Requirements

Resource requirements for this method match those for formulating the baseline contract cost estimate plus a few hours for interviews of PMO personnel.

4. Application

This method is used in the USAF Electronics Systems Division. No other DOD users of this type method were found during preparation of this handbook.

H. THE RISK FACTOR METHOD

1. General

The risk factor method is a determination of factors, or multipliers, by which to increase individual program element

costs. The purpose of this risk factor method is to determine a reasonable budget, above that resulting from a baseline cost estimate, to provide for cost growth anticipated as possible by the program manager. The method uses a WBS (or cost breakdown) based on a technical breakdown like Figure 12 (which is taken from [1] but does not necessarily conform to [14]).

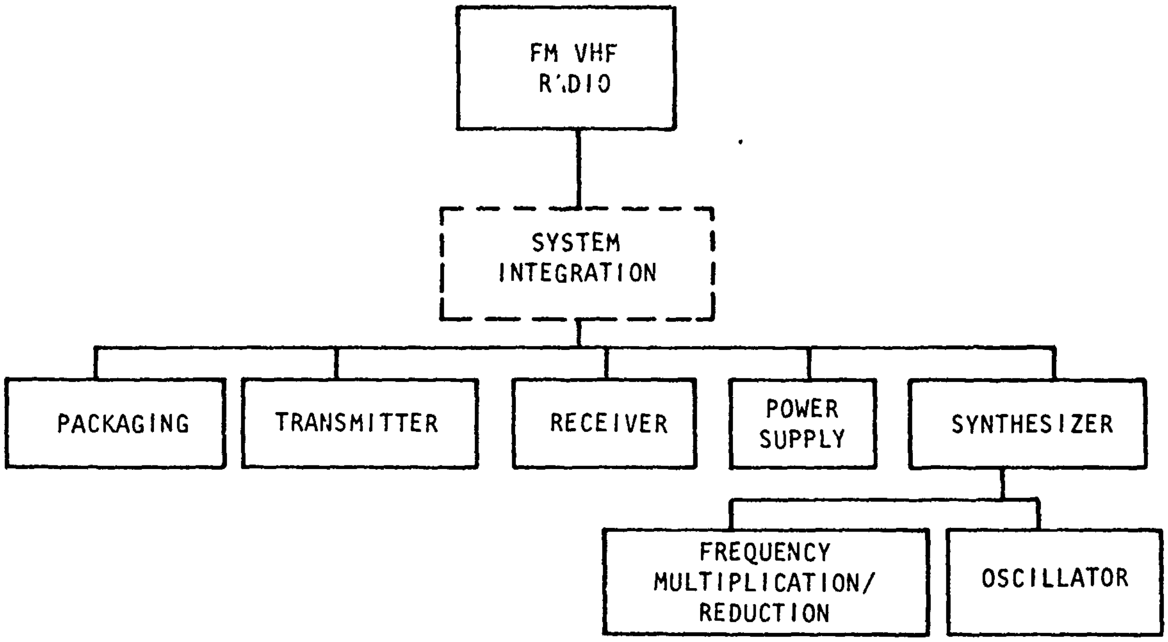


Figure 12

EXAMPLE WBS

The baseline cost estimate is developed for each cost element. Applying whatever considerations are useful, such as those discussed in [11], a risk factor is established, greater than 1, for each cost element. The estimate element costs are then multiplied by these risk factors to obtain the estimates used in the budget for providing a level of funding which will account for technical or other risk.

The assignment of risk factors is the key feature of this method and is the point at which it is both most demanding and has the least objective basis. There is little documented experience upon which the analyst can draw in order to substantiate his factor assignment. Since the application is multiplicative and since such factors cannot reasonably be stated to a greater accuracy than about $\pm$ 0.05, it is just as important as with other methods that the inputs result from a searching probe of highly experienced technical experts. In other words, the apparent simplicity of the method has not relaxed the demand that high quality personnel take key roles in the analysis. On the other hand, once a baseline cost estimate has been formulated by engineering cost estimating methods, the analysts should be able to prepare a cost estimate using risk factors in a relatively short time. The length of time will depend on the difficulty an analyst has in consulting his technical experts and on the level of breakdown of his WBS.

2. Input/Output

a. Input

The primary, and generally pre-existing, "input" of a risk factor assessment is the WBS or cost breakdown of a baseline cost estimate. The risk factors are formulated intuitively based upon analyst or subject matter expert experience and knowledge of program hazards. More detailed discussion of the thinking that might underlie risk factor determination can be found in [11].

b. Output

The "output" of a risk factor application is a budget or cost estimate increased over the baseline budget (or estimate) by an amount anticipated to be sufficient to accommodate otherwise indeterminate, but probable, program costs.

3. Resource Requirements

Resource requirements for this method can be quite flexible. Frequently the same cost estimator responsible for the baseline estimate provides the risk factor result in a few hours. It is assumed that his experience, coupled with his questioning of subject matter experts during formulation of the baseline estimate, is satisfactory.

4. Application

Risk factor methods are the most widely used of those supporting U.S. Army TRACE procedures (see Appendix I), and analysts practiced in carrying them out can be found in the cost analysis offices of any major Army development command.

LIST OF REFERENCES

1. Cost Uncertainty/Management Reserve Analysis, Cost Management and Technology Division, Directorate of Cost Analysis, Deputy for Comptroller, Armament Division, Eglin AFB, FL, January 1982, (#).

2. Crawford, L.P., LCDR USN, A Case Study in Risk/Decision Analysis, Defense Systems Management College, Fort Belvoir, VA, 1973, (AD A046651), (LD32644A).

3. Evriviades, M. Management Reserve Cost Estimating Relationship, Cost and Analysis Division, Directorate of Cost Analysis, Comptroller, Hanscom AFB, MA, March 1980 (#).

4. Grover, P.E., and Schneickert, G.D., MAJ USA, Total Risk Assessing Cost Estimate (TRACE): A Field Survey, Systems and Cost Analysis Department, School of Logistics Science, U.S. Army Logistics Management Center, Fort Lee, VA, (#).

5. Hackenbruch, D.J., Risk Assessment of Candidate Mobile Protected Gun Systems, Systems and Cost Analysis Directorate, U.S. Army Tank Automotive Command, May 1981. (#).

6. Hwang, J.D., Analysis of Risk for the Material Acquisition Process, Part I - Fundamentals, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1970, (AD 715 394), (LD 25933).

7. Hwang, J.D., Analysis of Risk for the Materiel Acquisition Process, Part II - Utility Theory, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1971, (AD 747 365), (LD 25933A).

8. Hwang, J.D., and Kodani, H.M., An Impact Assessment Algorithm for R&D Project Risk Analysis, U.S. Army Air Mobility R&D Laboratory, Ames Research Center, Moffet Field, CA, October 1973 (#).

9. Jordan, H.R., and Klein, M.R., An Application of Subjective Probabilities to the Problem of Uncertainty in Cost Analysis, Office of the Chief of Naval Operations, Resource Analysis Group, Systems Analysis Division, (OP-96D), Pentagon, Washington, D.C., November 1975, (ADA 105 780).

10. Kraemer, G.T., "Quick and Effective Risk Analysis," Transaction of the AACE Annual Meeting, 21st, Morgantown, WV, 1977, (#).

11. "Letter of Instruction (LOI) for Implementation of RDTE Cost Realism for Current and Future Development Programs," Office of the Deputy Chief of Staff for Research, Development and Acquisition, Department of the Army, Washington, D.C., 6 March 1975 (#).

12. "Letter of Instruction (LOI) for Implementation of the Total Risk Assessing Cost Estimate for Production (TRACE-P)", Headquarters, U.S. Army Material Development and Readiness Command, Alexandria, VA, 6 October 1982. (#).

13. McNichols, G.R., On the Treatment of Uncertainty in Parametric Costing, The School of Engineering and Applied Science, The George Washington University, Washington, D.C., February 1976, (#).

14. Military Standard, Work Breakdown Structure for Defense Material Items, 25 April, 1975, (MIL-STD 881A), (#).

15. NASA/Army XV-15 Tilt Rotor Research Aircraft Risk Analysis, XV-15 Tilt Rotor Research Aircraft Project Office, NASA--Ames Research Center, Moffet Field, CA, May 1974, (#).

16. Raiffa, H., Decision Analysis: Introductory Lectures on Choices Under Uncertainty, Addison - Wesley, 1968, (#).

17. "Risk Model Documentation," Letter from Directorate of Cost and Management Analysis, Comptroller, Headquarters Air Force Systems Command, Andrews AFB, MD, 1 June 1981 (#).

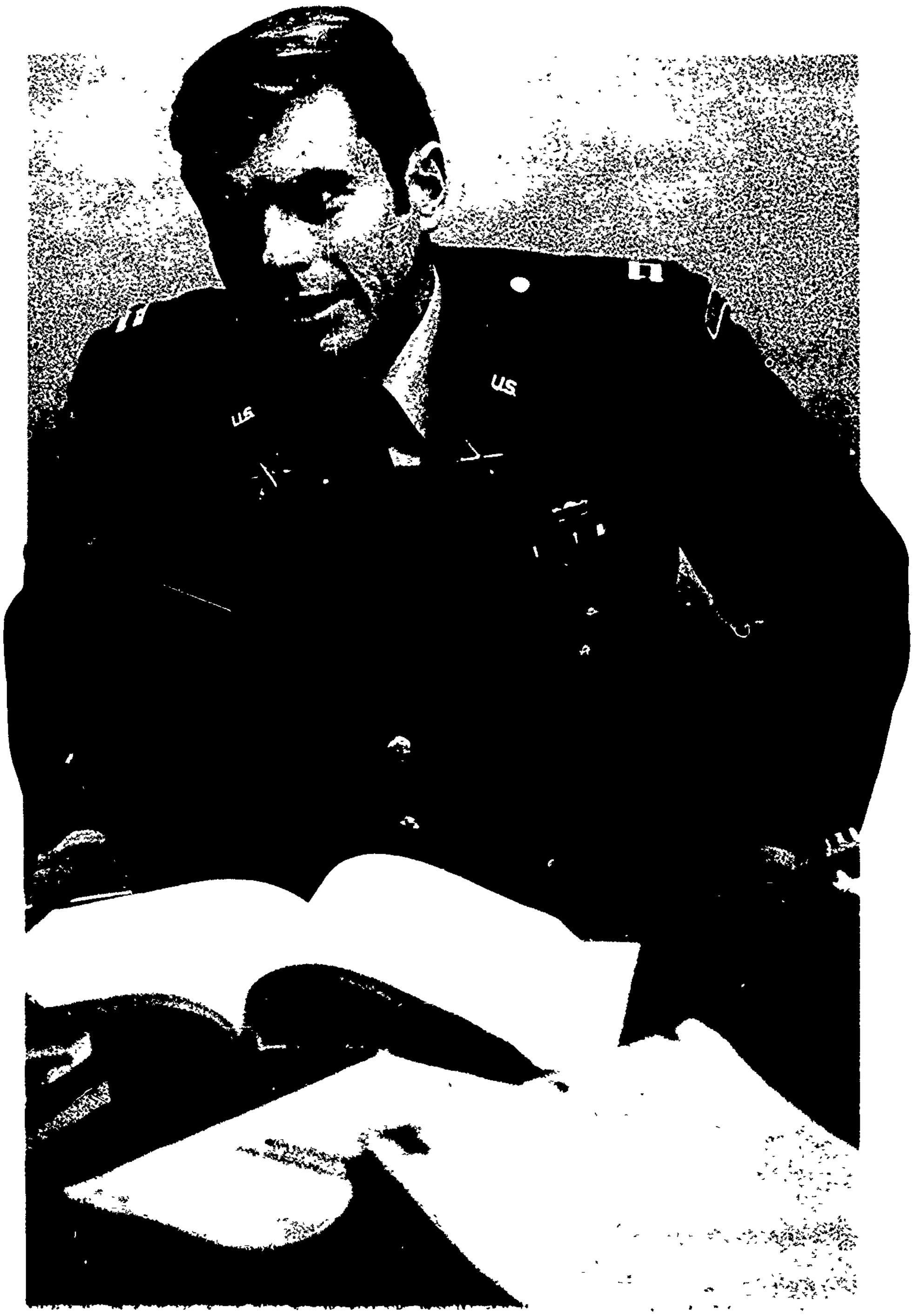
18. Sutherland, W., Fundamentals of Cost Uncertainty Analysis; Research Analysis Corporation, McLean, VA, 1971, (AD 881 975).

19. Sutherland, W., A Method of Combining Asymmetric Three-Valued Predictions of Time or Cost; Research Analysis Corporation, McLean, VA, July 1972, (AD 745 404).

20. Total Risk Assessing Cost Estimate (TRACE) Guide; John M. Cockerhand & Associates, Inc., Huntsville, AL, September 1979, (#).

(#) No AD/LD number for this document

HOW DO I SELECT A TECHNIQUE?



CHAPTER V

TECHNIQUE SELECTION

A. GENERAL

This chapter describes the circumstances influencing the selection of risk assessment methods and provides guidance which, while not making selection automatic, clarifies advantages and disadvantages of specific choices.

Section B discusses individual technique features for comparative purposes.

Section C briefly discusses conditions affecting the PMO which influence technique selection.

Section D discusses the purposes for which quantitative risk assessment can be used and shows that although these purposes are partially program-phase dependent, risk-laden decisions must be made throughout a program's life cycle. The section briefly describes the extent to which each technique supports the purposes listed.

Section E provides a table which integrates the discussions of the previous sections by characterizing each technique in terms of its requirements, its applicability, its theoretical soundness, and the amount of insight it provides.

B. TECHNIQUE FEATURES

This section summarizes material that, while partially discussed previously, should be clarified for comparative purposes. In this section the different features of specific techniques are identified and discussed. This discussion assists in later sections which describe how the conditions surrounding a program and the purposes for which a risk assessment is performed affect the desirability of one technique relative to another.

Features to be considered include:

- o Ease of use
- o Soundness of theory
- o Duration of support requirement
- o Versatility
- o Decision level suitability
- o PMO committment
- o Output content

The following paragraphs contrast the techniques by the cited features.

1. Ease of Use

Ease of use comprises an aggregate (subjective) evaluation consisting of: (1) theoretical difficulty, (2) volume, complexity, and difficulty of determining inputs, and (3) availability of software or other support. The most difficult technique to use, if only for the manpower required, is probably an (advanced) network assessment being applied for program control. Continual reporting is required and manpower must be permanently assigned. The next most difficult technique is the fully applied type of decision analysis exemplified in [3]. Decision analysis is of only moderate theoretical difficulty, but both subject matter and analytical insights are needed for establishing credible inputs and insuring full identification of problems and resolutions. The seemingly simple probabilities associated with the inputs are easily misreported, and sophisticated interview techniques are required. Of nearly equal difficulty is the standard network analysis. Its difficulty stems from the massiveness of its input and the difficulty inherent in program network modeling. Perhaps easier to use are the method-of-moments and WBS simulation methods. Sophisticated interview techniques are still necessary, but data input volume can be held to a more managable level (no more that 40 to 60 cost elements vs 200 to

1000 activities in a network and 100 or more problems in a decision analysis). The difficulty in understanding the theory of the method-of-moments, while not an obstacle to computation, makes it harder to use. Since software for support of method-of-moments analyses is not Government owned, the method is not as immediately available as those supported by Government-owned software. The last three methods--graphics, estimating relationships, and risk factors--are all fairly simple in concept and application: the graphic technique, because of its possible data acquisition difficulty, is judged to be the most difficult.

2. Soundness of Theory

Soundness of theory here covers both basic theoretical validity and the necessity for weakening assumptions. All techniques require some degree of simplifying, or weakening assumptions. For networks, assumptions are made that the selected levels of detail are indeed adequate and, usually, that inputs are statistically independent. Decision analytic methods have similar types of assumptions, and these two methods are probably the most theoretically valid, followed by WBS simulation. The latter may be considered to be a weaker method in that less detail is included and the effects of all risks on cost must be subjectively assessed. In the method of moments, it is necessary to assume a PDF type for total cost, which further weakens this technique. The use of the discontinuous halves of normal PDF's in the graphic method causes it to be judged even weaker. Because the estimating relationship method and the risk factor method both require substantial assumptions of comprehensive natures, the soundness of the theory for these methods is judged to be low, although they have gained widespread acceptance.

3. Duration of Support Requirement

Duration of support requirement varies from perpetual (for the advanced network assessment systems used for program control)

to hours (for risk factors and estimating relationships). Table 1 in Section E gives comparative range estimates.

4. Versatility

A more versatile technique can be used for a larger number of applications than a less versatile one. Applications are shown in Table 1.

5. Decision Level Suitability

The type of output produced by some methods can be considered of more or less value to any of three decision levels, i.e., within a PMO, at the program manager level, and at levels above the program manager. For levels within a PMO, program element managers will need assessments producing significantly detailed output descriptive of subelement risks. A program manager may be best served by more aggregated outputs descriptive of the major program elements but capable of describing subelement risks on an as-needed basis. Levels above the program manager will probably want more aggregated information providing insights into program general status and risks of major alternatives. See Table 1.

6. PMO Committment

For this handbook's purpose, PMO Committment represents the amount of attention required from a PM or his first level subordinates for a high quality assessment. The manhours shown in Table 1 are subjective estimates. For the network and the decision analysis assessments, the estimates are based on the PM's devoting approximately two hours of briefing and guidance time per week to the assessment team. For the method-of-moments, Probabilistic Event Analysis (PEA), WBS simulation estimating relationship, and risk factor methods, the reduced scope of the assessment is assumed to permit sufficient guidance on underlying program model structure (e.g., WBS) and assurance of reliability of data to require a small amount of the PM's time. Should the

method-of-moments, graphics, or risk factor methods be executed by the PM himself or his first level subordinates, of course more personal committment will be required. Should a graphics assessment be accomplished by a supporting analyst, the PM can probably reduce his committment to be commensurate with the rough approximation nature of such an assessment.

7. Output Content

A technique with a greater output content provides more breadth, depth, and understanding than one with outputs of a lesser content. While output content is associated with output quantity, it differs in that significant by-product benefit may accompany some assessment processes and not others.

Network techniques provide the direct benefits of insights into program element costs and risks resulting from developing activity PDF's at a selected level of detail. Additionally, assessments are inherently available for selected subsidiary parts of programs. The advanced network systems supplement such snapshot capability by providing a continuing status reporting and projective capabiltiy. The significant by-product of the detailed model-building process for a network assessment is the improvement in program definition (sometimes unrecognized) that results. The decision analysis methods inherently sacrifice detail for clarity. While the full scale assessment can be a superb analytical tool, it cannot provide to the PM or higher levels the breadth of a detailed network model. Its capability for showing tradeoff consequences cannot be approached by other techniques, however. Roughly the same output types result from method-of-moments, WBS simulation and graphic assessments in that some level of PDF is provided for each cost element. A well carried out Probabilistic Event Analysis provides probabilistic statements relative to problems that can approach the same level of detail. Estimating relationship and risk factor methods aggregate information and contain such structural weakness as to cause them to be judged lower in output content.

C. CONDITIONS AFFECTING THE PMO

1. General

While it might seem that comparing the characteristics of a required risky decision with the attributes of available assessment techniques might suffice for technique selection, a number of conditions external and internal to the PMO can modify technique desirability. Such conditions include high level policies, the military service and its policies, available program support organizations, management level of the PMO, resource availability, program phase, program schedule and technical complexity, and program criticality (both budgetary and military).

In general those programs that are of high criticality, high management level, well funded, complex, or any combination of these factors, can obtain any of the more demanding and rewarding techniques. Small programs headed by a "project engineer", "program coordinator", or "product manager", (for whom Table 1(b) is applicable) however, may be constrained by their own resources or the priorities of support organizations to use only the speedier and less detailed techniques. Even a well-funded, self contained program office may at times have subsidiary programs or time constraints which may make these speedier techniques appropriate.

The amount and depth of quantitative risk assessment obtained by self contained PMOs can usually be determined by the program manager. He is likely to need to call on the host command's systems analysis office for other than POM/Budget (TRACE) risk assessment, and he will need to train members of his staff or obtain contract services for ongoing risk assessment, such as for project control. For assessments of a periodic nature he can, at least in the Army, find experienced support offices, or he can obtain contract services.

The program manager of a matrix-supported PMO can usually determine the timing and depth of risk analysis provided by the host command (within the latter's priorities), but may have to obtain contract services if the systems analysis support office is overloaded. Continuing risk assessment most likely must come from a contractor. If a matrix support office is used, very often it may only be familiar with one method and will prefer to use that particular method.

Experience shows that the "project engineer/program coordinator/product manager" is unlikely to obtain support for risk assessment, and he often possesses insufficient funds to contract for it. The energetic and innovative PC can, however, utilize graphic, decision analytic, and/or method-of-moments techniques to obtain a better definition of the cost and schedule risks of his program.

2. Policy Requirements

It might be expected that higher level and military service policies would help in the selection of a risk assessment technique, and this is so to a limited degree. A listing of summarized and annotated higher and service level policy directives appears in Appendix H. For purposes of this chapter, the following overview suffices.

The higher level policies relating to risk assessment derive from OMB Circular A-109, DOD Directive 5000.1, and DOD Instructions 5000.2, 5000.38, and 7041.3. Only in the last is there any reference to quantitative risk assessment, and that has an informative rather than directive sense. On the other hand, the first four do make statements generally supporting quantitative risk assessment concepts. The extensive list of Army directives relating to quantitative risk assessment can be found in Appendix H. In summary, they specify that major and In Process Review (IPR) programs will supply Decision Risk Analyses (DRA's) for

each milestone review. While this does not explicitly specify the assessment techniques to be used, network analysis has become the customary technique employed for the DRA, therefore any technique selected for programs of similar criticality would probably be expected to be of similar quality.

The second explicit Army policy relating to a type of risk assessment stems from the TRACE budget procedure. The example given in the TRACE Letter of Instruction (LOI) [4] uses the risk factor method but an early paragrph permits use of any generally accepted technique. As with DOD directives, other Army directives are compatible with quantitative risk assessment concepts but do not require any particular techniques.

Of the USAF directives discussing risk assessment or related subjects, only AFR 173-11, paragraph 7.e., under Independent Cost Analysis (ICA) Methodology contains any directive sense for risk assessment. While its prescription that the ICA will use frequency distributions for cost ranges precludes employment of risk factors and estimating relationships, any of the other methods shown in this handbook meet the requirement.

The Naval Material Command has decided to evaluate the possibility of adapting the Army TRACE procedure to Navy use. To investigate this possibility, the Naval Air Systems Command has performed a few preliminary cost estimates using one or another of the procedures associated with TRACE and has published NAVAIR Instruction 7131.1, dated 21 April 1983; Subject: Management of Research, Development, Test, and Evaluation, Navy (RDT&E,N) Risk Cost Estimate Funding.

This instruction, however, prescribes only the procedures for holding, allocating, or reprogramming funding requested for the purpose of covering identified program uncertainties. It does not address methods for determining the amount to be requested.

Although the Naval Sea Systems Command has successfully employed at least two advanced network assessment systems for management control in a number of important programs, no directives on the subject of quantitative risk assessment were found during handbook preparation. Likewise, no NAVELEX directives were discovered.

The Headquarters, Naval Material Command, has published the Navy Program Manager's Guide, dated April 1983, which includes sections on Risk Management (page 3-21) and Budgeting for Program Risk. These sections recommend risk assessments be included in program acquisition strategies, but they do not specify any technique to be used.

D. Applications

Quantitative risk assessments have been proposed for assisting in at least the following decision categories:

- Program control
- Major planning decisions
- Acquisition strategy selection
- Technical alternative selection
- Contract structuring
- Source selection
- POM/Budget establishment

While for some applications no actual use of the application has been discovered during handbook preparation, there does not appear to be any obstacle preventing their use. All of these decision categories represent aspects of program management in which decisions must be made under conditions of uncertainty.

1. Program Control

"Catch phrases" in management can become a burden to the program manager. Some program managers have felt that risk

assessment has been used in a "catch phrase" way, and that the assessment they were required to undertake did not provide them with anything useful. Their expressed attitude was, "The assessment described a changing program in static terms. By the time the analysts were finished, they were analyzing a program that no longer existed. What I need is an analysis that responds to the changes."

Such statements lead to the important decision category Program Control. Program control means the monitoring of plans, schedules, and costs to ensure that standards are met and to allow for timely corrective action. The Cost Performance Report and Cost Schedule Status Reports made by contractors under the Selected Acquisition Information Management System and conforming to Cost/Schedule Control Systems Criteria were designed to provide contractors and program managers with information for management control. As valuable as such reports are, they leave it to reviewers to draw broad intuitive conclusions. Some risk assessment systems (see Appendix F and Reference [1]) have been implemented and used for management control for extended periods in the development of major weapons systems. Although it is impossible to measure the difference in the management performance that might have resulted without the systems, it can be said that the program managers were satisfied with the systems.

2. Planning

Planning overlaps some of the other decision categories (e.g., acquisition strategy selection), and it is perhaps the most pervasive of decision activities since planning is required during all program phases. For major planning decisions--those in which important program direction is determined--a program manager may be willing to invest significant resources and personal attention into understanding what his community of experts collectively believe are the chances of success of each alternative plan.

3. Acquisition Strategy Selection

Acquisition strategy selection is a category of early program decision in which risk assessment is likely to provide support in a somewhat indirect way. Certain aspects of acquisition strategy selection, such as the decision to undertake parallel R&D by competitive contractors rather than by selection of a single competitor, can be analyzed explicitly. On the other hand, the risk effects of selecting particular contract types may not be amendable to quantified analysis. In this case it would be premature to assert that a quantified risk assessment would do more than indicate the need or lack of need for a specific type of contract. See paragraph 5, on the following page, for discussion of how certain types of contracts can be structured using risk assessment.

4. Technical Alternative Selection

The next decision category amenable to quantitative risk analysis is technical alternative selection. Technical alternative selection must be undertaken soon after a mission need is identified, and it is during such concept formulation stages that uncertainty is greatest and risk assessment most needed. A program frequently passes through this phase before it is designated as a program or has a program manager. On the other hand, as a program passes through each subsequent phase, the manager must go through progressively narrower selections of technical alternatives, ranging from major weapon system technology alternatives to choices of components and materials. Each alternative represents a collection of large or small uncertainties regarding cost, schedule, technical performance, and program plan. In any event, there will be a community of experts on whom the manager will call for opinions on each aspect of the uncertainties associated with the alternatives. The manager will want an understanding of how the uncertainties relate to one another and how the alternatives compare.

5. Contract Structuring

Once an acquisition strategy has been selected that includes incentive type contracts, program management is faced with the decision of incentive fee determination. Since the purpose of incentive contracts is the sharing of risk between the contractor and the Government and the provision of an incentive to the contractor to control cost risk, an assessment of risk is needed. Appendix K describes a way for accomplishing this with any of the quantitative risk assessments producing a CDF.

6. Source Selection

Source selection often does not involve the program manager directly, yet source selection evaluation boards are required to evaluate risks as a determinant of selection. A quantified evaluation provides capability to substantiate the risk evaluation with improved credibility. Time constraints on a source selection process limit the detail of such an assessment and imply the desirability of using one of the less demanding methods. The earliest and latest program phases may seem to involve source selections of a less risky nature than does the development phase, but the deployment phase, for example, may require modification program source selections of a highly uncertain character.

7. Budget Formulation

Budget formulation is a decision category required on a periodic basis. The decision as to what level of budget to request can be made on the basis of a quantified evaluation of the risk of failing to achieve objectives with a given funding level. Implicit is the growing need for quantified risk assessment to support credible budget requests.

E. TECHNIQUE SELECTION CRITERIA

Tables 1(a) and (b) summarize and integrate the subjects discussed in previous sections so that a best fit of technique to

situation may be achieved. Table 1(a) provides criteria for a self contained or a designated, chartered, and matrix supported PMO, assuming the assessment is to address issues appropriate to the PM's attention. Table 1(b) provides criteria for a program coordinator, project engineer, or product manager (herein designated PC) to address of issues appropriate to him or to a time or resource constrained PM of a higher level program.

	COST 1/ ($)	TIME 1/ (WEEKS)	1/ SKILL 2/	1/ 3/ PMO COMMIT-MENT (MAN-HRS)	DECISION CATEGORIES: PROGRAM CONTROL	MAJOR PLANS	ACQUISITION STRATEGY	TECHNICAL ALTERNATIVE SELECTION	CONTRACT STRUCTURING	SOURCE SELECTION	POM BUDGET	THEORY SOUNDNESS	DECISION 5/ LEVEL	OUTPUT CONTENT
ADVANCED NETWORK	>100K	FULL	GS-14/15	FULL 4/ ~40	X	X	X	X	X		X	HIGH	1,2,3	VERY HIGH
STANDARD NETWORK	~35K	16-24	GS-14	~40		X	X	X	X		X	HIGH	2,3	HIGH
DECISION ANALYSIS	~70K	16-24	GS-14/15	~40		X	X	X			X	HIGH	2,3	HIGH
PROBABILISTIC EVENT ANALYSIS	~35K	2-4	GS-14	~8							X	LOW	2	MODERATE TO LOW
METHOD OF MOMENTS	~3K	2-4	GS-13	~4					X	X		MODERATE	2	MODERATE
WBS SIMULATION	~3K	2-4	GS-13	~4					X	X		MODERATE	2	MODERATE
GRAPHICS	1-2K	1-4	GS-13	~1								LOW	2	MODERATE
ESTIMATING RELATIONSHIPS	<1K	1-2	GS-13	~4							X	VERY LOW	2	LOW
RISK FACTORS	<1K	1-2	GS-13	~4							X	VERY LOW	2	LOW

NOTES: 1 ESTIMATED INITIAL COST
2. BOTH ANALYST AND TEAM CHIEF AND PMO CONTROL
3. DIRECT PM ATTENTION
4. FULL TIME GS-14/15 PLUS 2 GS-12/13
5. LEVELS WHERE TECHNIQUE CAN BE USED FOR DECISION MAKING: 1-INTERNAL TO PMO; 2-AT PM LEVEL; 3-ABOVE PM LEVEL

TABLE 1 (a)

TECHNIQUE SELECTION CRITERIA
FOR
MAJOR PROGRAMS

	COST 1/ ($)	TIME 1/ (WEEKS)	1/ SKILL 2/	1/ 3/ PMO COMMIT-MENT (MAN-HRS)	DECISION CATEGORIES							THEORY SOUNDNESS	DECISION LEVEL	OUTPUT CONTENT
					PROGRAM CONTROL	MAJOR PLANS	ACQUISITION STRATEGY	TECHNICAL ALTERNATIVE SELECTION	CONTRACT STRUCTURING	SOURCE SELECTION	POM BUDGET			
PROBABILISTIC EVENT ANALYSIS	~3K	2-4	GS-13	8							X	LOW	PC	MODERATE TO LOW
METHOD OF MOMENTS	~3K	2-4	GS-13	4		X	X	X	X	X	X	MODERATE	PC	MODERATE
WBS SIMULATION	~3K	2-4	GS-13	~4		X	X	X	X	X	X	MODERATE	PC	MODERATE
GRAPHICS	1-2K	1-4	GS-13	2		X	X	X	X	X	X	LOW	PC	MODERATE
ESTIMATING RELATIONSHIPS	<1K	1-2	GS-13	~2							X	VERY LOW	PC	LOW
RISK FACTORS	<1K	1-2		~2							X	VERY LOW	PC	LOW

NOTES: 1. ESTIMATED INITIAL COST
2. EITHER SUPPORT ANALYST OR PC
3. PC NOT ACTING AS ANALYST

TABLE 1 (b)
TECHNIQUE SELECTION CRITERIA
FOR
LESS-THAN-MAJOR PROGRAMS

LIST OF REFERENCES

1. Feiler, A.M., The TRANSIM V Manual, Volume I, Introduction to TRANSIM V, UCLA-ENG-7848, UCLA School of Engineering and Applied Science, Pasadena, CA., September 1978, (ADA059925)

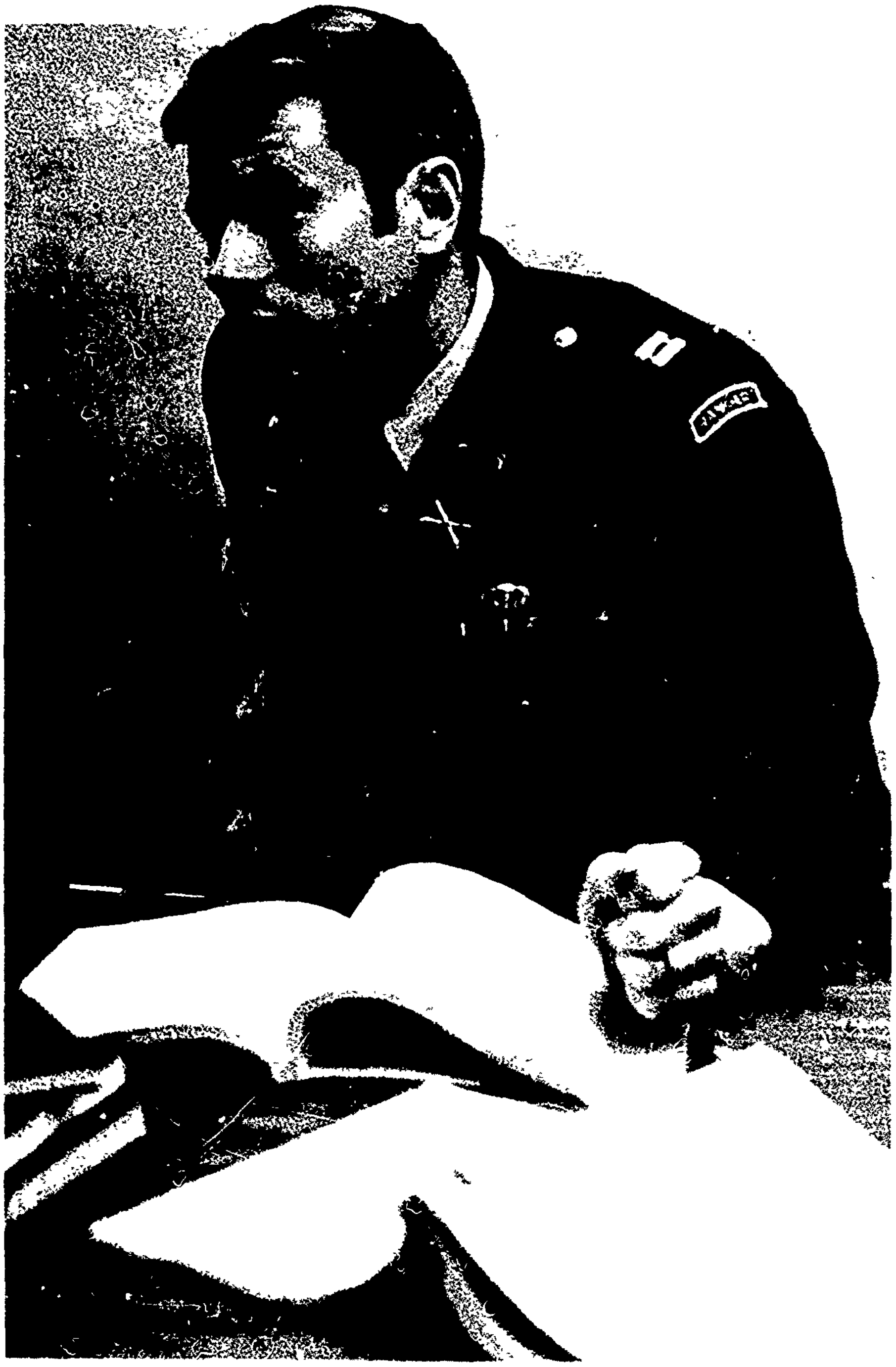
2. Feiler, A.M., The TRANSIM V Manual, Volume II, TRANSIM User's Manual, UCLA-ENG-7855, UCLA School of Engineering and Applied Science, Pasadena, CA., September 1978 (ADA 060397)

3. Hwang, J.D., and Kodani, H.M., An Impact Assessment Algorithm for R&D Project Risk Analysis, U.S. Army Air Mobility R&D Laboratory, Ames Research Center, Moffett Field, CA, October 1973, (#).

4. "Letter of Instruction (LOI) for Implementation of RDT&E Cost Realism for Current and Future Development Programs", Office of the Deputy Chief of Staff for Research, Development and Acquisition, Department of the Army, Washington, D.C., 6 March 1975, (#).

(#) No AD/LD number for this document.

HOW DO I IMPLEMENT?



CHAPTER VI

IMPLEMENTATION

A. General

The program manager who wishes to obtain a quantitative risk assessement can obtain it from within his own PMO, through a functional support office of his host command, from his prime contractor, or from a support services contractor. Each source has been found appropriate and has been used by at least one program manager, but it was determined during preparation of this handbook that most PMO personnel preferred to use functional support offices. Some criteria considered when selecting a source for accomplishing a quantitative risk assessment include: (1) the need for objectivity, (2) difficulty of keeping less closely coupled organizations current on dynamic programs, and (3) the requirement for familiarity with technical and programmatic problems, practices, and polices. Some program managers find standardization desirable, believing that risk assessments may be better understood by reviewing authorities and can be used to compare programs. Table 2 summarizes the application of these criteria to the sources of risk assessment support. In Table 2 Capability refers to the knowledge of risk assessment techniques, and Objectivity is self explanatory. Standardization means the use of a locally standard technique and of uniformly applied criteria. Responsiveness and Familiarity aggregate the ideas of technical and program knowledge with adaptability to program changes.

TABLE 2

CRITERIA

Source	Capability	Objectivity	Standardization	Responsiveness and Familiarity
PMO	occasional, Limited	purpose dependent	enforceable	high
MTRX	service specific	service specific	service specific	variable
PRIME	variable	questionable	enforceable	high
SSC	available	purpose dependent	enforceable	available

The entries in Table 2 deserve some expansion. The term "service specific" indicates that those qualities vary by service as a result of inherent organizational relationships.

The entry for PMO capability, "occasional, limited," recognizes that some PMOs contain members who have developed the interest and skills to perform risk assessment. The burden of other duties usually has limited the scope of assessments to the more summary types. On the other hand, in the Naval Sea Systems Command, support services contractors have developed systems to assist the PMO in its continuing management of project risk. In one case the systems were operated by full time PMO members in a program of the type having to depend on matrix organizations for much of its daily function. The program was, however, one of such high visibility and cost as to justify the effort and expenditure required for this application.

The entry for Prime Capability, "variable," recognizes that some prime contractors may not have developed a significant risk assessment capability.

In the objectivity column, the entries "purpose-dependent" appear because neither a member of the PMO nor a support services

contractor are likely to provide results that are any more objective than are desired by the controlling manager.

The entry "enforceable" under Standardization indicates that orders to PMO members and contracts to contractors can require the use of a specific type of technique. Unless the requirements are specified, it can be expected that the resulting risk assessments from these sources will not be standardized. Risk assessments done by the functional support groups will probably be accomplished in a form and format standardized within that command.

In the final analysis, the first source from which a program manager should seek a comprehensive risk assessment is the Government (host command) matrix organization. Should that source be unable to provide it, and if the capability or resources are not available within the PMO, then because of capabiltiy and objectivity, probably the next best alternative is a support services contractor. Summary level assessment can be accomplished by PMO technical personnel if care is taken with gathering information.

A more complete list of service, commercial, and academic centers of research and expertise is included as Appendix J.

B. Service Considerations

1. All Services

For information of a general nature or which may cross service lines, contact may be made with:

- The Research Directorate (DRI-R)
  Defense Systems Management College
  Fort Belvoir, VA 22060,
  (703) 664-5783
  AV 354-5783

2. Army

In general, Army materiel development commands provide risk assessment support to resident PMO's through one or two analysis organizations. The names vary, but all are given titles that closely approximate "Cost and Systems Analysis." Sometimes the two functions are separated and sometimes not, but in general, a systems analysis unit performs Decision Risk Analyses (DRA's) and risk assessments of a programmatic nature, and a cost analysis unit performs Total Risk Assessing Cost Estimate (TRACE) related assessments for budgetary purposes.

Each command tends to adopt and become most proficient in the use of particular techniques. For example, most systems analysis offices have adopted network analysis using the VERT computer model as the vehicle for conducting DRAs, while MICOM has developed a capability to employ network analysis using the RISNET model. Most of the cost analysis offfices make use of the method of risk factors to formulate TRACE's.

Should a program manager wish to undertake a more sophisticated and detailed risk asessment or risk analysis than a command systems analysis office is prepared to provide, the latter can identify support services contractors capable of such analyses, as most systems analysis offices have employed contractors to assist them during overload situations.

For additional information on Army policy and practices or for other assistance, Department of the Army personnel may contact:

- HQ DARCOM
  DRCCP-ER (Mr. Richard Baker)
  5001 Eisenhower Avenue
  Alexandria, VA 22333
  (202) 274-8030
  AV 284-8030

- U.S. Army Material System Analysis Activity Army Procurement Research Office
  Fort Lee, VA 23801
  (804) 734-2027
  AV 687-2027

3. Air Force

The comptroller's office at Armament Division maintains a network analysis computer program referred to as "the RISK model".

At many Air Force Systems Command locations, risk assessment is the interest primarily of the various controller offices, each of which develops estimates for engineering change order/management reserves.

Points of contact for Department of the Air Force personnel needing additional information on Air Force and local policies/procedures are the following:

- HQ AFSC/ACCE
  Andrews Air Force Base, D.C. 20334
  (301) 981-4306
  AV 858-4306

- ASD/ACCR
  Wright-Patterson, AFB, OH 45433
  (513) 255-5904
  AV 785-5904

- ESD/ACC
  Hanscom AFB, MA 01731
  (617) 861-2677
  AV 478-2677

- AD/ACC
  Eglin AFB, FL 32542
  (904) 882-2151
  AV 872-2151

- Air Force Business Management Research Center (BMRC)
  Wright-Patterson AFB, OH 45433
  (513) 255-6221
  AV 785-6221

4. Navy

The functional support groups of Navy Systems Commands have relatively little experience in conducting formal risk assessment. A survey supporting preparation of this handbook found that the Navy has generally depended on support services contractors to conduct risk assessments.

For personnel of the Department of the Navy more information can be obtained by contacting the following:

- Executive Director
Navy Office for Acquisition Research
(Located at DSMC, Fort Belvoir, VA 22060)
(703) 664-2817
AV 354-2817

- Naval Sea Systems Command
SEA-901
Washington, D.C. 20362
(202) 692-8600
AV 222-8600

- Naval Air Systems Command
AIR-104A
Washington, D.C. 20361
(202) 692-0066
AV 222-0066

APPENDICES

A. Bibliography

B. Definition of Terms

C. Acronyms

D. Quantifying Expert Opinion

E. Statistical Independence

F. Technique Descriptions

G. Presentation of Results

H. Policy Directives

I. Budget Policies Incorporating Risk Assessment

J. Centers of Research

K. Application to Contract Structure

L. Applications of Methods Outputs

APPENDIX A

BIBLIOGRAPHY

This bibliography of the risk analysis literature is divided into five categories: basic discussion of general risk assessment procedures, theoretical discussion of mathematical techniques, case studies, administrative procedures for risk management or budget procedures, and other topics.

A matrix format for each category is included for easy access to the literature. In the matrix, literature is coded for the following subjects: acquisition phase specifically mentioned or most appropriate, management area (budgeting, planning, scheduling, controlling, pricing, and strategy selection), risk variable(s), and analytical approach discussed above in the text.

Each work is numbered in each appropriate matrix, and the full bibliographic information for that numbered work is provided in the accompanying alphabetical list. The full bibliographic information includes, where it is known, AD/LD number for obtaining publications through the Defense Technical Information Center or the Defense Logistic Information Exchange, and annotations as well as the standard publication information. Asterisks appear beside entries (core items) providing information of key importance to understanding a technique or serving as a superior example of application.

BASIC DISCUSSION

*1. Antunes, Moore, et al, Ed., Army Programs Decision Risk Analysis (DRA) Handbook, U.S. Army Logistics Management Center, Fort Lee, VA, (DARCOM Handbook 11-1.1-79), 1979, (#).
Subjective probability methods discussed: Choice between gambles pdf/cdf, standard lottery, Churchman/Ackoff, Delphi. Describes role of DRA in material acquisition process, as well as methods of performing DRA's.

2. Atzinger, E., et al, Compendium on Risk Analysis Techniques, DARCOM Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, 1972, (AD 746 245), (LD 28463).
Subjective probability methods discussed: Choice between gambles pdf/cdf, standard lottery, Churchman/Ackoff, Delphi.

3. Babiarz, A.A., CAPT, USAF, and Giedras, P.W., CAPT USAF, A Model To Predict Final Cost Growth in a Weapon System Development Program, The School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1975, (AD A016 040), (LD 34803A).
Replicates Glover-Lenz application of Martin Cost Model which incorporates uncertainty and cost analysis addressing final weapon development cost. Measures uncertainty by flatness of probability distribution, defined as entropy.

4. Banash, R.C., and Hurta, D.W., "Risk Analysis in Weapons Development"; Proceedings of the 1972 U.S. Army Operations Research Symposium --'Risk Analysis', U.S. Army Operations Research Office - Durham, Durham, NC, May 1972, (AD 748 407), (LD 27863).
Discusses organization of risk analysis team. Distinguishes risk analysis and decision risk analysis. Defines decision risk analysis for U.S. Army. Subjective probability assessment method--Delphi.

*5. Barclay, Brown, Kelly, Peterson, Phillips, and Selvidge, Handbook for Decision Analysis, Decisions and Designs Inc., McLean, VA, 1977, (#).
Provides introduction to basic concepts and operations of decision analysis. Includes Bayesian concepts.

6. Barclay, D.H., MAJ USA, The Project Manager and Systems Analysis, Defense Systems Management College, Fort Belvoir, VA, 1974, (LD 32631A).

1/ * Core Item
(#) No AD/LD number identified

BASIC DISCUSSION

7. Bevelhymer, H.L., CAPT USAF, A Proposed Methodology for Weapon System Development Risk Assessment, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1973, (AD 766 885), (LD 29823).

Developed and tested methodology for obtaining input distributions from routine contractor-supplied data. Used VERT model to develop network. Applied method of moments. Tested methodology on actual weapon system in FSD. Results inconclusive, but merit further application.

8. Brown, E.L., An Application of Simulation Networking Techniques in Operational Test Design and Evaluation, Georgia Institute of Technology, May 1975, (AD A024 204).

9. Busse, D.E., MAJ USAF, A Cost Performance Forecasting Model, Air Command and Staff College, Air University, Maxwell AFB, AL, May 1977, (AD B019 568).

Estimate at Completion (EAC) Projection. Uses power curve and regression, plus Cost Performance Report (CPR) information.

10. Cost Uncertainty/Management Reserve Analysis, Cost Management and Technology Division, Directorate of Cost Analysis, Deputy for Comptroller, Armament Division, Eglin AFB, FL, January 1982, (#).

WBS, subjective probability method discussed: centralized decision using expert advice. Risk Model Documentation.

11. Cox, L., and Bohn, M., Report on the Development of a Prototype Computerized Model and Data Base for Use in Comparing Acquisition Strategies; The Analytic Sciences Corporation, Arlington, VA (TR-1375), January 1981, (#).

Interactive computer model which compares acquisition strategies based on weapon system oncept and program objectives.

12. Crawford, L.P., LCDR USN, A Case Study in Risk Decision Analysis, Defense Systems Management College, Fort Belvoir, VA 1973, (AD A046 651), (LD 32644A).

Description of fictitious application to production decision for missile system, using decision analysis. Subjective probability assessment decentralized to group members.

1/ * Core Item
(#) No AD/LD number identified

13. Davis, G.W., The Dilemma of Uncertainties Associated with Cost Estimating in the Project Management Office, Defense Systems Management College, Fort Belvoir, VA, 1976, (AD A029 274).

14. Dienemann, P., Estimating Cost Uncertainty Using Monte Carlo Techniques, The RAND Corporation, Santa Monica, CA, January 1966, (AD 629 082).

15. Dodson, E.N., "Risk Analysis in the Acquisition of BMD Systems", Proceedings of the 1972 U.S. Army Operations Research Symposium--'Risk Analysis', U.S. Army Operations Research Office-Durham, Durham, NC, May 1972, (AD 748 407).

16. Donnell, M.L., and Ulvila, J.W., Decision Analysis of Advanced Scout Helicopter Candidates; Decisons and Designs, Inc., McLean, VA, February 1980, (AD 081 483).
Ilustrates use of technical alternative selection using multi-attribute utility theory but no decision-analysis-explicit consideration of risk.

17. Edgar, J. D., LTC USAF, "Controlling Murphy: How to Budget for Program Risk, Concepts - The Journal of Defense Systems Acquisition Management, Volume 5, Number 3, Defense Systems Management College, Fort Belvoir, VA 1982, (#).

18. Feiler, A.M., The TRANSIM V Manual, Volume I, Introduction to TRANSIM V, UCLA School of Engineering and Applied Science, Pasadena, CA, UCLA-ENG-7848, September 1978, (AD A 059 925); The TRANSIM V Manual, Volume II, TRANSIM User's Manual,UCLA School of Engineering and Applied Science, Pasadena, CA, UCLA-ENG-7855, September 1978, (AD A 060 397).

19. Feltus, E.E., Risk Analysis in the Engineering Process, Industry/Joint Services Automatic Test Conference and Workshop on Advanced Test Technology, San Diego, CA, 1978, (#).
Broad treatment to stimulate interest in risk analysis.

20. Hayes, R.A., CAPT USAF, An Evaluation of a Bayesian Approach to Compute Estimates-at-Completion for Weapon Systems Programs, Air University, Air Force Institute of Technology, Wright-Patterson AFB, OH, December 1977, (AD A056 502).
Analysis of Cost Performance Report (CPR) information based on Bayesian inference. Made separate variance predictions.

1/ * Core Item
(#) No AD/LD number identified

BASIC DISCUSSION

21. Howard, T.W., "Methodology for Developing Total Risk Assessing Cost Estimate (TRACE)", U.S. Army Logistics Management Center, Fort Lee, VA, ALM-63-4476-H3, November 1978, (#).
Instructional pamphlet.

22. Husic, F.J., Cost Uncertainty Analysis, Research Analysis Corporation, McLean, VA, May 1967, (AD 686 770).

23. Hutzler, W.P., Nelson, J.R., Rei, R.Y., and Francisco, C.M., Non Nuclear Air to Surface Ordnance For The Future: An Approach to Propulsion Technology Risk Assessment, The RAND Corporation, Santa Monica, CA, October 1982, (#).
Time of arrival regression to predict magnitude of risk in conceptual programs.

*24.Hwang, J.D., Analysis of Risk for the Material Acquisition Process, Part I - Fundamentals, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1970; (AD 715 394), (LD 25933).
Subjective probability method is choice between gambles pdf/cdf and Delphi; presents several techniques of statistical decision theory and subjective judgement collection; also decision analysis methods for contract definition and concepts formulation phases.

25. Hwang, J.D., Analysis of Risk for the Material Acquisition Process, Part II - Utility Theory, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1971, (AD 747365), (LD 25933A).
Presents discussion of utility theory, lotteries and techniques to elicit utility functions. Subjective probability method is choice between gambles (pdf).

26. Hwang, J.D., "Risk Analysis Versus Systems Analysis in the Materiel Acquisition Process", Proceedings of the Tenth Annual United States Army Operations Research Symposium, 26-28 May 1971, U.S. Army Research Office, Research Triangle Park, NC, 1971, (AD 731 795), (LD 25933B).

27. Hwang, J.D., and Banash, R.C., An Introduction to Decision/Risk Analysis, U.S. Army Armament Command, Rock Island, IL, 1971, (LD 27240).

28. Hwang, J.D., and Kodani, H.M., An Impact Assessment Algorithm for R&D Project Risk Analysis, U.S. Army Air Mobility R&D Laboratory, Ames Research Center, Moffett Field, CA, October 1973, (#).

1? * Core Item
(#) No AD/LD number identified

Offers approach to risk analysis data collection. Provides automated algorithm to compute success probability and cost impact. Unspecified subjective probability method.

29. Hwang, J.D., and Shumway, C.R., "Decision Risk Analysis for Research and Development", Proceedings of the 1972 U.S. Army Operations Research Symposium-- "Risk Analysis", U.S. Army Operations Research Office-Durham, Durham, NC, May 1972, (AD 748 407).

30. Jeas, W.C., MAJ USAF, Development of Weapon Systems: A Process of Technical Uncertainty Identification and Resolution, Defense Systems Management College, Fort Belvoir, VA, 1976, (LD 36396A).

31. Jordan, H.R., and Klein, M.R., An Application of Subjective Probabilities to the Problem of Uncertainty in Cost Analysis, Office of the Chief of Naval Operations, Research Analysis Group, Systems Analysis Division, Washington, D.C., November 1975, (AD A105 780).

Independence of cost element uncertainties is needed in this simulation of WBS using Beta distributed cost element. Documentation of SPET (Subjective Probability Estimation Technique) Model.

32. Kerns, W.R., "Risk and Uncertainty: State of the Art in Application"; paper presented at the Federal Acquisition Research Symposium, Washington, D.C., 1982, (#).

33. Knight, J.R., Comparison of PERT and PERT/COST with RISCA and RISNET from a User-Manager Standpoint, U.S. Army Logistics Management Center (Florida Institute of Technology), Fort Lee, VA, 1974, (LD 31523).

34. Kraemer, G.T., "A Successful Quantitative Risk Assessment Technique", Martin, Rowe, Sherman, Ed. Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs, University of Southern California, Colorado Springs, CO, 1981, (#).

Iterative use of graphic technique for functional management control and contract structuring.

35. Kraemer, G.T., "Quick and Effective Risk Analysis", Transaction of the AACE Annual Meeting, 21st, Morgantown, WV, 1977, (#).

Quick, effective basic method using normal graph paper.

1/ * Core Item
(#) No AD/LD number identified

36. Larew, R.E., "Decision Making in Construction Operations", in Martin, Rowe, Sherman, Ed. Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs; University of Southern California, Colorado Springs, CO, 1981, (#).
Attacks common distributions recommends using the RS distribution; not directly usable without further development.

37. Lieber, R.S., "New Approaches for Quantifying Risk and Determining Sharing Arrangements", Paper Presented at the Federal Acquisition Research Symposium, Washington, D.C., 1980, (#).
Basis for negotiating share and for risk management. PDF analysis.

38. Lochry, R.R. COL USAF, et al, Final Report of the USAF Academy Risk Analysis Study Team, Deputy for Systems, Aeronautical Systems Division, Wright-Patterson AFB, OH, August 1971, (AD 729 223).
Subjective probability method--Delphi.

39. MacCrimmon, K.R., and Ryavec, C.A., An Analytical Study of the PERT Assumptions, The RAND Corporation, Santa Monica, CA, December 1962, (AD 293 423).
Critique of PERT Assumptions.

40. McNichols, G.R., "A Procedure for Cost-Risk Assessment", in Martin, Rowe, Sherman, Ed. Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs; University of Southern California, Colorado Springs, CO, 1981, (#).
Unspecified subjective probability assessment methods. Good discussion by developer of method-of-moments techniques.

41. McNichols, G.R., "Independent Parametric Costing, What? Why? How?", Proceedings Spring Conference of the American Institute of Industrial Engineering, Pg. 3-11; AIIE, Norcross, GA, 1975;
Examines concepts and principles of independent parametric costing philosophy.

42. McNichols, G.R., Hutzler, W.P., Insley, P.A., and Atkinson, A.S., "Concurrency: The Program Manager's Dilemma", Paper Presented at the Federal Acquisition Research Symposium, Washington, D.C., 1982, (#).

43. Morris, J.M. and D'Amore, R.J., Aggregating and Communicating Uncertainty, Rome Air Development Center, Griffiss AFB, NY, RADC-TR-80-113; April 1980, (AD A086 987).

1/ * Core Item
(#) No AD/LD number identified

Subjective probability presentation. Methods of producing well-founded estimates. Calibration of subjective probability estimates. Excellent bibliography on subjective probability.

44. Nelson, J.R., Performance/Schedule/Cost Tradeoffs and Risk Analysis for the Acquisition of Aircraft Turbine Engines: Applications of R-1288-PR Methodology; The RAND Corporation, Santa Monica, CA, June 1975, (AD A013 729).
Technique to quantify technical advancement and to trade cost, performance and risk; regression basis.

45. Norton, M., Abeyta, R., and Grover, P., Production Risk Assessing Methodology (PRAM), U.S. Armv Materiel Systems Analysis Activity, Fort Lee, VA, 1982, (#).
TRACE to minimize disruptive programming in pre- and early production phase.

46. O'Flaherty, J., Identification and Estimation of High Cost or High Risk Elements, Research Analysis Corporation, McLean, VA, December 1980, (AD 884 533).
Rudimentary discussion of WBS. Discusses level of detail in WBS's.

47. Oraski, H.C., et al, Acquisition Cost Estimating Using Simulation, Naval Training Equipment Center, Orlando, FL, September 1975, (AD A 015 624).

48. Powell, N., "Risk Analysis Methodology for Engineering Development Contracts," Proceedings of the Fourteenth Annual United States Army Operations Research Symposium (AORS), Vol. I, U.S. Army of Logistics Center, Fort Lee, VA, (AD B009 955L).

49. Preliminary Analysis of Technical Risk and Cost Uncertainty in Selected DARPA Programs, Meridian Corporation, Falls Church, VA, 1981, (AD A107 402-Final Report), (AD A103 792--Interim Report)).
Complex mix of decision analysis and administrative procedure.

50. Press, S.J., and Harman, A.J., Methodology for Subjective Assessment of Technological Advancement, The RAND Corporation, Santa Monica, CA, (R-1375), 1975, (#).

51. Program Appraisal Methodology, Air Force Armament Systems Laboratory, Eglin AFB, FL, (AFATL-TF-79-72), August 1979, (AD B049 513L).

1/ * Core Item
(#) No AD/LD number identified

Risk almost peripheral issue in multi-attribute utility model.

52. RISCA 3 Documentation, U.S. Army Logistics Management Center, Fort Lee, VA, (ALM-63-3737-H2), (#).

53. Risk Model Documentation, Directorate of Cost and Management Analysis, DCS/Comptroller, Air Force Systems Command, Andrews AFB, MD, 1 June 1981.

54. RISNET Analyst's Guide, John M. Cockerham and Associates, Inc., Huntsville, AL, (#).

55. Robinson, J. N., CAPT USAF, Sequential Probability Ratio Tests of the Scale Parameter Between Two Weibull Distributions with Known Shape Parameter, Air University, Air Force Institute of Technology, Wright-Patterson AFB, OH, December 1976, (AD A034 999).

A research experimental design.

56. Rowe, A.J., "Methods to Predict Cost Overruns in the Acquisition Process", Paper Presented at the Federal Acquisition Research Symposium, Washington, D.C., 1982, (#).

Proposes a scale for quantifying technical complexity; descriptive overview.

57. Selman, J.H.N., and Selman, V., "Operations Research for Risk Analysis Evaluation", Proceedings of the 1972 U.S. Army Operations Research Symposium--Risk Analysis, U.S. Army Operations Research Office-Durham, Durham, NC, May 1972, (AD 748 407).

58. Strauch, R., Risk Assessment as a Subjective Process, The RAND Corporation, Santa Monica, CA, 1980, (LD 48338A).

Discussion of need to couple judgement and methodology and to use models suited to situation.

*59. Sutherland, W., Fundamentals of Cost Uncertainty Analysis, Research Analysis Corporation, McLean, VA, 1971, (AD 881 975).

Fairly good but elementary treatment of mathematics of adding probabilities, unspecified subjective probability assessment method.

60. Thompson, W.E., "Risk Implications for Cost Growth in Weapon System Acquisition Programs", Concepts - The Journal of Defense Systems Acquisition Management, Volume 5, Number 2; Defense Systems Management College, Fort Belvoir, VA, 1982, (#).

1/ * Core Item
(#) No AD/LD number identified

BASIC DISCUSSION

General discussion and implications. Unspecified subjective probability assessment method.

61. Total Risk Assessing Cost Estimate (TRACE) Guide, John M. Cockerham & Associates, Inc., Huntsville, AL, September 1979, (#).

62. Varnell, A.K., et al, "Risk Analysis in Military R&D Projects", Proceedings of the 1972 U.S. Army Operations Research Symposium--Risk Analysis, U.S. Army Operations Research Office-Durham, Durham, NC, (AD 748 407).

63. Venture Evaluation and Review Technique (VERT), (ALM-63-5260-H), U.S. Army Logistics Management Center, Ft. Lee, VA, November 1979, (#).
See also G.L. Moeller, Venture Evaluation and Review Technique, Decision Models Directorate, U.S. Army Armament Material Readiness Command, Rock Island, IL, November 1979, (AD 076 600).

64. Venzke, G.A., LTC USA, Implementation of Risk Assessment in the Total Risk Assessing Cost Estimate (TRACE), U.S. Army War College, Carlisle Barracks, PA, 1977, (LD 39206A).

*65.Wilder, J.J., An Analytical Method for Cost Risk Analysis, Grumman Aerospace Corporation, Bethpage, NY, (PDR-OT-T77-12), 1977, (#).
Quick but effective. Quantifies uncertainty by generating moments and estimating bounded error.

66. Wilder, J.J., and Black, R., "Using Moments in Cost Risk Analysis", in Martin, Rowe, Sherman, Ed, Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs, University of Southern California, Colorado Springs, CO, 1981, (#).

67. Wilder, J.J., and Black, R.L., "Determining Cost Uncertainty in Bottoms-Up Estimating", Paper Presented at Federal Acquisition Research Symposium, Washington, DC, 1982, (#).
Dependency treated. Triangular, uniform and beta distribution treated.

68. Williams, J.B., CAPT USAF, An Analysis of Risk Assessment Within Aeronautical Systems Division, The School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1971, (LD 27458).

1/ * Core Item
(#) No AD/LD number identified

69. Worm, G.H., "An Application of Risk Analysis - Uses, Problems and Pitfalls",in Martin, Rowe, Sherman, Ed. Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs, University of Southern California, Colorado Springs, CO, 1981, (#).

70. Worm, G.H., Application of Risk Analysis in the Acquisition of Major Weapon Systems, Clemson University, Department of Mathematical Sciences, Clemson, SC, 1980, (LD 49124A).
Easily used, computer supported method for determining contract incentives.

71. Zettler, W.T., MAJ USAF, Capital Budgeting Decisions: A Study of Theory Versus Application, Air Command and Staff College, Air University, Maxwell AFB, AL, April 1979, (AD B039 480L).
Research on utilization of capital budgeting. Methods include types of risk analysis.

72. Zschau, E.V.W., Project Modelling: A Technique for Estimating Time-Cost-Performance Trade-Offs In System Development Projects, The RAND Corporation, Santa Monica, CA, July 1969, (AD 691 810).
Based on mathematical programming, and utilizes dual variable approach.

1/ * Core Item
(#) No AD/LD number identified

BASIC DISCUCSION

	ACQUISITION PHASE				MANAGEMENT AREA						RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
*1	X	X				X	X				X	X	X	X	X	X	X			MATHNET/SOLVANT/RISCA/TRACE
2	X	X				X	X				X	X	X	X		X				PERT/RISCA
3	X	X				X			X		X								X	
4	X	X			X	X	X				X	X		X		X				
5	X	X				X									X					
6																				
7		X		X				X						X		X				VERT/RISCA
8			X			X					X	X	X	X		X				
9								X			X								X	
10	X	X			X	X					X					X			X	RISK DOCUMENTATION
11		X	X	X		X				X	X	X	X							USER PROPRIETARY
12				X		X					X	X							X	
13	X	X	X	X		X		X			X						X			
14						X					X					X				FORTRAN
15											X	X		X						
16	X					X							X		X				X	
17		X			X									X	X	X	X			TRACE
18	X	X		X		X					X		X	X						TRANSIM DOCUMENTATION
19		X	X			X			X							X				
20		X		X				X			X									OWN FORTRAN
21		X			X						X			X		X			X	RISCA, VERT, TRANCENET, RISNET, ET.AL
22	X	X	X	X		X					X			X				X		ISOC (RAC)
23	X					X					X	X	X							

BASIC DISCUSSION

	ACQUISITION PHASE				MANAGEMENT AREA					RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
*24	X	X		X		X	X		X	X	X	X	X		X				X	
*25	X	X	X			X	X				X	X	X		X					
*26		X			X	X	X				X									
27	X	X				X	X				X	X	X		X					
28	X	X				X	X				X	X	X	X	X	X				GERT
29		X				X	X				X									
30		X	X	X		X				X			X							
31	X	X	X	X		X					X					X				SPET DOCUMENTATION
32											X									
33		X	X			X					X	X	X	X		X				PERT/RISNET/RISCA COMPARISON
34		X		X		X					X					X				
35																				
36				X					X		X									
37									X		X								X	
38						X		X			X	X		X		X				PERT, CPM, GERT
39																				
40	X	X	X	X		X		X		X	X		X					X		
41											X								X	
42											X	X								
43																				
44	X					X					X	X	X							
45				X							X						X			
46	X	X				X					X									

BASIC DISCUSSION

	ACQUISITION PHASE				MANAGEMENT AREA						RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
47		X			X				X							X			X	
48		X				X	X				X	X								STATNET
49		X			^	X	X				X	X	X	X			X			DYNAMO
50	X	X				[illegible]							X	X					X	
51		X	X		X						X									
52		X				X	X				X	X		X		X				RISCA DOCUMENTATION
53	X	X				X					X						X			RISK DOCUMENTATION
54	X	X			X	X	X				X	X		X		X				RISNET DOCUMENTATION
55			X			X		X					X						X	
56	X	X		X		X					X									
57											X	X		X						
58																				
59						X					X					X	X			
60	X	X	X	X		X	X	X			X	X								
61	X	X	X	X		X	X				X	X		X	X	X				
62		X			X	X	X				X									
63	X	X		X		X	X	X			X	X	X	X						VERT DOCUMENTATION
64		X									X	X								
65	X	X	X	X		X	X				X	X	X					X		
66	X	X		X		X					X	X						X		
67	X	X	X	X		X					X							X		
68											X									
69				X		X			X		X									

BASIC DISCUSSION

	ACQUISITION PHASE				MANAGEMENT AREA						RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
70	X	X							X	X	X							X		
71						X					X									
72	X	X	X	X		X	X	X			X	X		X					X	

1. Asher, N.J., and Maggelet, T.F., On Estimating the Cost Growth of Weapon Systems, Institute for Defense Analysis, Arlington, VA, June 1980, (AD A094 693), (LD 49447A).

2. Atzinger, E., et al, Compendium on Risk Analysis Techniques, DARCOM Materiel Systems Analysis Activitiy, Aberdeen Proving Ground, MD, 1972, (AD 746 245), (LD 28463)..
Subjective probability methods are: Choice between gambles pdf/cdf, standard lottery, Churchman/ Ackoff, Delphi.

3. Babiarz, A.A., CAPT USAF, and Giedras, P.W., CAPT USAF, A Model To Predict Final Cost Growth in a Weapon System Development Program, The School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1975, (AD A 016 040), (LD 34803A).
Replicates Glover-Lenz application of Martin Cost Model which incorporates uncertainty and cost analysis addressing final weapon development cost. Measures uncertainty by flatness of probability distribution, defined as entropy.

4. Barclay, Brown, Kelly, Peterson, Phillips, and Selvidge, Handbook for Decision Analysis, Decisions and Designs, Inc., McLean, VA, 1977, (#).
Provides introduction to basic concepts and operations of decision analysis; includes Bayesian methods.

5. Bevelhymer, H.L., CAPT USAF, A Proposed Methodology for Weapon System Development Risk Assessment, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1973, (AD 766 885), (LD 29823).
Developed and tested methodology for obtaining input distributions from routine contractor-supplied data. Used VERT model to develop network. Applied method-of-moments. Tested methodology on actual weapon system in FSD. Results inconclusive, but merit further application.

6. Chervaney, N.L., et al, Analysis and Design of Computer-Based Management Information Systems: An Evaluation of Risk Analysis Decision Aids, University of Minnesota, Minneapolis, MN, September 1974, (AD A006 749).
Research on usefulness of risk analysis decision aids.

7. Dienemann, P., Estimating Cost Uncertainty Using Monte Carlo Techniques, The RAND Corporation, Santa Monica, CA, January 1966, (AD 629 082).

8. Donnell, M.L., and Ulvila, J.W., Decision Analysis of Advanced Scout Helicopter Candidates; Decisons and Designs, Inc., McLean, VA, February 1980, (AD 081 483).
Decision analysis applied to technical alternative selection using multi-attribute utility analysis, but no explicit consideration of risk.

9. Edwards, W., John, R., and Stillwell, W., Research on the Technology of Inference and Decision, Social Science Research Institute, University of Southern California, Los Angeles, CA, November 1977, (AD A056 921).
Graphic subjective probability assessment method.

10. Graves, S.B., A Monte Carlo Risk Analysis of Life Cycle Cost, Air Force Institute of Technology, Wright-Patterson AFB, OH, September 1975, (AD A021 677).
Reliability and maintainability measures used as variables showing technical risk share ratio, award fee determinations.

11. Hayes, R.A., CAPT USAF, An Evaluation of a Bayesian Approach to Compute Estimates-at-Completion for Weapon Systems Programs, Air University, Air Force Institute of Technology, Wright-Patterson AFB, OH, December 1977, (AD A056 502).
Analysis of Cost Performance Report (CPR) and information based on Bayesian inference. Made separate variance predictions.

12. Hwang, J.D., Analysis of Risk for the Material Acquisition Process, Part I - Fundamentals, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1970, (AD 715 394), (LD 25933).
Subjective probability method is choice between gambles pdf/cdf and Delphi. Presents several techniques of statistical decision theory and subjective judgement collection. Risk analyses methods of contract definition and concepts formulation phases.

13. Hwang, J.D., Analysis of Risk for the Material Acquisition Process, Part II - Utility Theory, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1971, (AD 747365), (LD 25933A).
Presents discussion of utility theory, lotteries and techniques to elicit utility functions. Subjective probability method is choice between gambles pdf.

14. Hwang, J.D., and Kodani, H.M., An Impact Assessment Algorithm for R&D Project Risk Analysis, U.S. Army Air Mobility R&D Laboratory, Ames Research Center, Moffett Field, CA, October 1973, (#).
Offers approach to risk analysis data collection, provides automated algorithm to compute success probability and cost impact. Unspecified subjective probability assessment method.

15. Larew, R.E., "Decision Making in Construction Operations", in Martin, Rowe, Sherman, Ed. Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs; University of Southern California, Colorado Springs, CO, 1981, (#).
Attacks common distributions. Recommends using the RS distribution.

16. Martin, M.D., A Conceptual Cost Model for Uncertainty Parameters Affecting Negotiated, Sole-Source, Development Contracts, University of Oklahoma, Norman, OK, 1971, (AD A035 482), (LD 37971A).

17. McNichols, G.R., "Macro Models For the Treatment of Uncertainty in Parametric Costing", Proceedings Ninth Annual Meeting, Southeastern Chapter, Institute of Management Sciences, Pg. 57-66, Clemson University, Clemson, SC, 1973, (#).
Discusses use of method of moments in macro models; subjective probability assessment method used is unspecified interview.

18. McNichols, G.R., "Independent Parametric Costing, What? Why? How?", Proceedings Spring Conference of the American Institute of Industrial Engineering, Pg. 3-11; AIIE, Norcross, GA, 1975, (#).
Examines concepts and principals of independent parametric costing philosophy.

19. McNichols, G.R., On the Treatment of Uncertainty in Parametric Costing, The School of Engineering and Applied Science, The George Washington University, Washington, D.C., February 1976, (#).
The seminal work on method of moments in parametric costing.

20. McNichols, G.R., "Treatment of Uncertainty in Life Cycle Costing", Proceedings 1979 Annual Reliability and Maintainability Symposium, IEEE, 1979, (#).

21. McNichols, G.R., "Uncertainties of LCC Predictions", Paper Presented at NATO Advanced Study Institute on Electronic System Effectiveness and Life Cycle Costing, Norwich, England, 1982, (#).
Analytical method for aggregating LCC component and subsystem costs.

22. Montgomery, D.C., Callahan, L.G., and Wadsworth, H.M., Application of Decision/Risk Analysis in Operational Tests and Evaluation, The School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, GA, September 1975, (AD A024 205).
Report on four theses. Last shows novel linear programming approach. Unspecified subjective probability assessment methods.

23. Moskowitz, H., and Sarin, R.K., "Improving Conditional Probability Assessment for Forecasting and Decision Making in Weapon System Acquisition", in Martin, Rowe, Sherman, Ed. Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs, University of Southern California, Colorado Springs, CO, 1981, (#).

24. Robinson, J. N., CAPT USAF, Sequential Probability Ratio Tests of the Scale Parameter Between Two Weibull Distributions with Known Shape Parameter, Air University, Air Force Institute of Technology, Wright-Patterson AFB, OH, December 1976, (AD A034 999).
A research experimental design.

25. Rowe, A.J., "Methods to Predict Cost Overruns in the Acquisition Process", Paper presented at the Federal Acquisition Research Symposium, Washington, D.C., 1982, (#).
Proposes a scale for quantifying technical complexity. Descriptive overview.

26. Sutherland, W., Adding Cost Estimates That are Not Symmetric About the Most Likely Value, Research Analysis Corporation, McLean, VA, 1971, (AD 883 232).
Method for summing estimates without a computer that include high and low estimates.

27. Sutherland, W., A Method for Combining Asymmetric Three-Valued Predictions of Time or Cost, Research Analysis Corporation, McLean, VA, July 1972, (AD 745 404).
Graphically derives moments of Weibull distribution based on asymmetry coefficient.

28. Timson, F.S. and Tihansky, D.P., Confidence in Estimated Airframe Costs: Uncertainty Assessment in Aggregated Predictions, The RAND Corporation, Santa Monica, CA, October 1972, (#).
Unspecified subjective probability assessment method.

29. Wilder, J.J., An Analytical Method for Cost Risk Analysis, Grumman Aerospace Corporation, Bethpage, NY, (PDR-OT-T77-12), 1977, (#).
Quick but effective; quantifies uncertainty by generating moments and estimating error bounds.

30. Wilder, J.J., and Black, R., "Using Moments in Cost Risk Analysis", in Martin, Rowe, Sherman, Ed. Proceedings Management of Risk and Uncertainty in the Acquisition of Major Programs, University of Southern California, Colorado Springs, CO, 1981, (#).

31. Worm, G.H., Application of Risk Analysis in the Acquisition of Major Weapon Systems, Clemson University, Department of Mathematical Sciences, Clemson, SC, 1980, (LD 49124A).
Easily used, computer supported method for determining contract incentives.

32. Worm, G.H., Applied Risk Analysis With Dependence Among Cost Components, Clemson University, Clemson, SC, 1981, (AD A119 617).

33. Zettler, W.T., MAJ USAF, Capital Budgeting Decisions: A Study of Theory Versus Application, Air Command and Staff College, Air University, Maxwell AFB, AL, April 1979, (AD B039 480L).
   Research on utilization of capital budgeting. Methods include types of risk analysis.

34. Zschau, E.V.W., Project Modelling: A Technique for Estimating Time-Cost-Performance Trade-Offs In System Development Projects, The RAND Corporation, Santa Monica, CA, July 1969, (AD 691 810).
   Based on Mathematical Programming, and utilizes dual variable approach.

No AD/LD number identified.

THEORETICAL DISCUSSION

	ACQUISITION PHASE				MANAGEMENT AREA						RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
1	X				X						X	X							X	
2	X	X				X	X				X	X	X	X		X				PERT/RISCA
3	X	X				X			X		X								X	
*4	X	X				X									X					
5		X		X				X						X		X				VERT/RISCA
6						X														
7						X					X					X				FORTRAN
8	X					X							X		X				X	
9																				
10		X	X						X		X					X				
11		X		X				X			X									OWN/FORTRAN
*12	X	X		X		X	X		X	X	X	X	X		X				X	
*13	X	X	X			X	X				X	X	X		X					
14	X	X				X	X				X	X	X	X	X	X				GERT
15				X					X		X									
16	X	X	X			X					X								X	
*17						X		X			X				X			X		
18											X								X	
*19						X					X							X		
20						X		X			X							X		
*21						X		X			X							X		
22			X		X	X					X	X	X	X		X			X	FORTRAN, VERT
23																				

THEORETICAL DISCUSSION

	ACQUISITION PHASE				MANAGEMENT AREA						RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
24			X			X		X					X						X	
25	X	X		X		X					X									
*26											X					X				
*27														X		X		X		
28		X				X					X						X			
*29	X	X	X	X		X	X				X	X	X					X		
30	X	X		X		X					X	X						X		
31	X	X							X	X	X							X		
32		X		X					X								X	X		
33						X						X								
34	X	X	X	X		X	X	X			X	X		X					X	

CASE STUDIES

1. AN/TPQ-36 Mortar Artillery Locating Radar Transport Configuration Decision Risk Analysis, Systems Analysis Office, U.S. Army Electronics Command, January 1975, (AD B011 925L).
Exhaustive qualitative application.

2. Air Traffic Management Automated Center (ATMAC) Concept Formulation Study: Computer Model, Volume 1, Hughes Aircraft Company, Ground Systems Division, Fullerton, CA, 1974, (AD 916 524L).

3. Amdor, S.L., CAPT USAF, and Kilgore, R.R., CAPT USAF, Quantitative Risk Assessment: A Test Case, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1974, (AD 777 585), (LD 31450).

4. Babiarz, A.A., CAPT USAF, and Giedras, P.W., CAPT USAF, A Model To Predict Final Cost Growth in a Weapon System Development Program, The School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1975, (AD A016 040), (LD 34803A).
Replicates Glover-Lenz application of Martin Cost Model which incorporates uncertainty and cost analysis addressing final weapon development cost. Measures uncertainty by flatness of probability distribution, defined as entropy.

*5. Barclay, Brown, Kelly, Peterson, Phillips, and Selvidge, Handbook for Decision Analysis, Decisions and Designs, Inc., McLean, VA, 1977, (#).
Provides introduction to basic concepts and operations of decision analysis. Includes Bayesian methods.

6. Bevelhymer, H.L., CAPT USAF, A Proposed Methodology for Weapon System Development Risk Assessment, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1973, (AD 766885), (LD 29823).
Developed and tested methodology for obtaining input distributions from routine contractor-supplied data. Used VERT model to develop network. Applied method of moments. Tested methodology on actual weapon system in FSD. Results inconclusive, but merit further application.

7. Carodine, F., Laube, H., Esslinger, W.H., Jr., and Blue, D.L., Improved Law Cost and Schedule Risk Analysis, Systems Analysis Office, U.S. Army Missile Command, Redstone Arsenal, AL, October 1975, (AD B010 641L).
Standard Decision Risk Analysis (DRA) for Anti-Tank Missile.

8. Cost/Schedule Risk Analysis of Engineering Development Phase for Army User Equipment of GPS, ARINC Research Corporation, Santa Ana, CA, April 1977, (AD A051 919).

Analysis of schedule risk taking most likely times from Baseline Cost Estimate but for maximum and minimum using assumed percentage of most likely; GPS system--Example of derivative costing.

9. Cox, L., and Bohn, M., Report on the Development of a Prototype Computerized Model and Data Base for Use in Comparing Acquisition Strategies, The Analytic Sciences Corporation, Arlington, VA, (TR-1375), January 1981, (#).
Interactive computer model which compares acquisition strategies based on the weapon system concept and program objectives.

10. Dodson, E.N., "Risk Analysis in the Acquisition of BMD Systems," Proceedings of the 1972 U.S. Army Operation Research Symposium--Risk Analysis, U.S. Army Operations Research Office-Durham, Durham, NC, May 1972, (AD 748 407).

11. Donnell, M.L., and Ulvila, J.W., Decision Analysis of Advanced Scout Helicopter Candidates; Decisons and Designs, Inc., McLean, VA, February 1980, (AD 081 483).
Illustrates use of decision analysis for technical alternative selection using multi-attribute utility theory, but no explicit consideration of risk.

12. Glover, W.L., CAPT USAF, and Lenz, J.O., CAPT USAF, A Cost Growth Model for Weapon System Development Programs, The School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1974, (AD 785 438), (LD 32006A).
Missile cost control application. Subjective probability method used is Delphi.

13. Graves, S.B., A Monte Carlo Analysis of Life Cycle Cost, Air Force Institute of Technology, Wright-Patterson AFB, OH, September 1975 (AD A021 677).
Unspecified subjective probability assessment method.

14. Grayson, A.S., CAPT USAF, and Lanclos, H.J., CAPT USAF, A Methodology for Subjective Assessment of Probability Distributions, The School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1976, (AD A032 536), (LD 37757A).
Subjective probability assessment and content analysis.

15. Hackenbruch, D.J., and VanHorn, A., Decision Risk Analysis for the M-1 Tank System, Systems and Cost Analysis Directorate, U.S. Army Tank Automative Command, July 1981, (#).

16. Hackenbruch, D.J., Initial Operational Capability Schedule Risk Analysis for Fighting Vehicle System, Systems and Cost Analysis Directorate, U.S. Army Tank Automative Command, March 1981, (#).

17. Hackenbruch, D.J., Risk Assessment of Candidate Mobile Protected Gun Systems, Systems and Cost Analysis Directorate, U.S. Army Tank Automative Command, May 1981, (#).

18. Hayes, R.A., CAPT USAF, An Evaluation of a Bayesian Approach to Compute Estimates-at-Completion for Weapon Systems Programs, Air University, Air Force Institute of Technology, Wright-Patterson AFB, OH, December 1977, (AD A056 502).
Analysis of Cost Performance Report (CPR) information based on Bayesian inference. Made separate variance predictions.

19. Hutzler, W.P., Nelson, J.R., Rei, R.Y., and Francisco, C.M., Non Nuclear Air to Surface Ordnance For The Future: An Approach to Propulsion Technology Risk Assessment, The RAND Corporation, Santa Monica, CA, October 1982.
Time of arrival regression to predict magnitude of risk in conceputal programs. Risk associated with achieving technical advance in schedule and cost.

20. Hwang, J.D., et al, A Risk Analysis of the Improved Cobra Armament Program, U.S. Army Air Mobility R&D Laboratory, Ames Research Center, Moffett Field, CA, June 1972, (#).
Unspecified subjective probability assessment method.

21. Mazza, T.N., Paarman, A.W., and Netzler, M., Risk Analysis of the Army Production Plan for Self-Propelled Howitzers, U.S. Army Armament Command, Systems Analysis Directorate, Rock Island, IL, June 1976, (AD A026 681).
Simple network defined using Baseline Cost Estimate values. Analysis method not stated, subjective probability assessment used is centralized decision with group advice.

22. McGinnis, J.P., LTC USA, and Kirschbaum, A.I., CAPT USAF, "TRACE Risk Assessment and Program Execution", Defense Systems Management College, Fort Belvoir, VA, December 1981, (#).
Evaluation of TRACE. Good insight on experience gained in use of TRACE since inception.

23. Montgomery, D.C., Callahan, L.G., and Wadsworth, H.M., Application of Decision/Risk Analysis in Operational Tests and Evaluation, The School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, GA, September 1975, (AD A024 205).
Report on four theses. Last shows novel linear programming approach. Unspecified subjective probability assessment methods.

24. NASA/Army XV-15 Tilt Rotor Research Aircraft Risk Analysis, XV-15 Tilt Rotor Research Aircraft Project Office, NASA-Ames Research Center, Moffett Field, CA, May 1974, (#).
Unspecified subjective probability assessments method.

CASE STUDIES

25. Netzler, M., Risk Analysis of the U.S. Army 155 MM Cannon-Launched Guided Projecticle Program; U.S. Army Materiel Readiness Command, Systems Analysis Directorate, Rock Island, IL, 1974, (AD A019 932), (AD 350 11A).
Simple application to projectile program.

26. Niemeyer, W.A., Emanuel, J.C., Kusterer, E.T., and Vegoda, R.J., Technical Risk of Extended Configurations of the M113A1E1, U.S. Army Material Systems Analysis Activity, Aberdeen Proving Ground, MD, July 1978, (LD 42808A).

27. Norton, M., Abeyta, R., and Grover, P., Production Risk Assessing Methodology (PRAM), U.S. Army Materiel Systems Analysis Activity, Fort Lee, VA, 1982, (#).
TRACE to minimize disruptive reprogramming in pre- and early production phases.

28. Preliminary Analysis of Technical Risk and Cost Uncertainty in Selected DARPA Programs, Meridian Corporation, Falls Church, VA, 1981, (AD A107 402-Final Report, AD A103 792-Interim Report).
Complex mix of decision analysis and administrative procedure.

29. Relationship Between Cost and Schedule Risk, U.S. Army Electronics Command, Systems Analysis Office, Fort Monmouth. NJ, 1975, (LD 40117A).
Cost risk as multiple of schedule and fixed cost.

30. Risk Analysis of a V/STOL Tilt Rotor Research Aircraft, U.S. Army Air Mobility Research and Development Laboratory and Tilt Rotor Research Aircraft Projects Office, Ames Research Center, Moffett Field, CA, March 1972, (#).
Unspecified subjective probability assessment method.

31. Robinson, J. N., CAPT USAF, Sequential Probability Ratio Tests of the Scale Parameter Between Two Weibull Distributions with Known Shape Parameter, Air University, Air Force Institute of Technology, Wright-Patterson AFB, OH, December 1976, (AD A034 999).
A research experimental design.

32. Seamands, R.E., and Hwang, J.D., Analysis of Risk for the 105MM, Light, Towed, Soft Recoil Howitzer, XM 204, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1970.
Unspecified subjective probability assessment method.

33. Shapiro, P. B., and Kearley, K.L., Technical Report 78-13, Decision Risk Analysis: COBRA XM230E1 Program, U.S. Army Troop and Aviation Readiness Command, Directorate for Plans and Systems Analysis, Systems Analysis Division, St. Louis, MO; October 1978, (#).
Investigates risk of integrated gun into airframe using exhaustive model but brief analysis; some VERT description.

CASE STUDIES

34. Smith, J.A., Decision Risk Analysis (DRA) on the Development of the Bridge-Erection Boat for the Ribbon Bridge, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, VA, May 1975, (AD B005 061L).
Technical alternative selection. Comparison of simple acquisition strategy.

35. Tate, R. O., Remotely Piloted Vehicle (RPV); Management Reserve for the Investment Phase, U.S. Army Aviation Research and Development Command, St. Louis, MO, 1981, (AD B061 737L).

36. Thomas, T.N., MAJ USA, VERT - A Risk Analysis Technique for Program Managers, Defense Systems Management College, Fort Belvoir, VA, 1977, (AD A04 7620), (LD 40483A).

37. Timson, F.S., Measurement of Technical Performance in Weapon System Development Programs: A Subject Probability Approach, The RAND Corporation (RM-5207-ARPA), Santa Monica, CA, 1968, (#).
Subjective probability method is choice between gambles, pdf/cdf, standard lottery.

38. Tyburski, D., Olson, H., and Bernstein, R., Decision Risk Analysis, AN/TPQ-37 Artillery Locating Radar, U.S. Army Electronics Command, Systems Analysis Office, Fort Monmouth, NJ, 1975, (LD 33186A).
Poor documentation but fair decision aid.

* Core Item.
# No AD/LD number identified.

CASE STUDIES

	ACQUISITION PHASE				MANAGEMENT AREA						RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
1		X				X							X							
2		X				X	X				X	X		X		X				MATHNET
3		X				X	X	X			X	X		X		X				
4	X	X				X			X		X								X	
*5	X	X					X								X					
6		X		X					X					X		X				VERT/RISCA
7		X			X		X				X	X		X		X				STATNET
8		X	X			X					X	X		X		X				SOLVENET
9		X	X	X		X				X	X	X	X							USER PROPRIETARY
10											X	X		X						
11						X							X		X					
12		X				X		X			X									
13		X	X						X		X					X				
14																				
15				X			X				X	X	X	X		X				VERT
16				X		X	X					X		X		X				VERT
17	X					X					X	X	X						X	
18		X		X				X			X									OWN FORTRAN
19	X					X					X	X	X						X	
20		X				X					X	X		X	X	X				GERT
21		X				X						X		X						
22		X	X	X	X	X					X								X	
23			X		X	X					X	X	X	X		X			X	

CASE STUDIES

	ACQUISITION PHASE				MANAGEMENT AREA						RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
24		X				X					X	X		X	X	X				GERT
25		X									X	X		X		X				VERT
26													X							
27				X							X						X			
28		X			X	X	X				X	X	X	X			X			DYNAMO
29		X				X	X				X	X							X	
30		X				X					X	X		X	X	X				GERT
31			X			X		X					X						X	
32	X					X		X			X	X	X		X					GERT
33		X				X	X			X	X	X		X		X				VERT
34		X				X					X			X		X				MATHNET
35		X		X	X	X					X			X		X				VERT
36		X	X	X	X	X	X	X			X	X	X	X		X				VERT
37	X	X	X	X		X	X	X			X	X	X			X				
38			X							X				X		X				VERT

ADMINISTRATIVE PROCEDURES

*1. Antunes, Moore, Ed., Army Programs Decision Risk Analysis (DRA) Handbook, U.S. Army Logistics Management Center, Fort Lee, VA, DARCOM Handbook 11-1.1-79, 1979, (#).
Subjective probability methods discussed: Choice between gambles pdf/cdf, standard lottery, Churchman/Ackoff, Delphi. Describes role of DRA in material acquisition process, as well as methods of performing DRA's.

2. Edgar, J. D., LTC USAF, "Controlling Murphy: How to Budget for Program Risk", Concepts - The Journal of Defense Systems Acquisition Management, Volume 5, Number 3, Defense Systems Management College, Fort Belvoir, VA 1982, (#).

3. Evriviades, M., Management Reserve Cost Estimating Relationship, Cost Estimating and Analysis Division, Directorate of Cost Analysis, Comptroller, Hanscom AFB, MA, March 1980, (#).
Determination of MR Percent at ESD; regression.

4. Howard, T.W., "Methodology for Developing Total Risk Assessing Cost Estimate (TRACE)", U.S. Army Logistics Management Center, Ft. Lee, VA, ALM-63-4476-H3, November 1978, (#).
Instructional pamphlet.

*5. Hwang, J.D., Analysis of Risk for the Material Acquisition Process, Part I - Fundamentals, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1970, (AD 715 394), (LD 25933).
Subjective probability method is choice between gambles pdf/cdf and Delphi. Presents several techniques of statistical decision theory and subjective judgement collection. Decision analysis methods of contract definition and concept formulation phases.

6. McNichols, G.R., "Cost-Risk Procedures for Weapon System Risk Analysis", 1981 Proceedings: Annual Reliability and Mainainability Symposium, IEEE, 1981, (#).

7. Program Appraisal Methodology, Air Force Armament Systems Laboratory, Eglin AFB, FL, AFATL-TF-79-72; August 1979, (AD B049 513).
Risk almost peripheral issue and not considered in TRACE-like context.

8. Total Risk Assessing Cost Estimate (TRACE) Guide; John M. Cockerham & Associates, Inc., Huntsville, AL, September 1979, (#).

* Core Item.
\# No AD/LD number identified.

ADMIN. PROCEDURE

	ACQUISITION PHASE				MANAGEMENT AREA						RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
1	X	X				X	X				X	X	X	X	X	X	X			MATHNET/SOLVEDET/RISCA/TRACE
2		X			X									X	X	X	X			TRACE
3		X			X	X					X									
4		X			X						X			X		X				RISCA, VERT, TRACENET, RISNET, ET. AL
*5	X	X		X		X	X		X	X	X	X	X		X					
6	X	X	X	X		X		X			X		X							
7		X	X		X						X									
8	X	X	X	X		X	X				X	X		X	X	X				

OTHER TOPICS

1. Amdor, S.L., CAPT USAF, and Kilgore, R.R., CAPT USAF; Quantitative Risk Assessment: A Test Case, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, OH, March 1974, (AD 777 585), (LD 31450).

2. Fraker, J.R., "Network Models for Risk Analysis", in Martin, Rowe, Sherman, Ed. Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs, University of Southern California, Colorado Springs, CO, 1981, (#).
Short background on two network software sets (RISCA and VERT) with some history.

3. Grover, P.G., and Schneickert, G.D., MAJ USA, Total Risk Assessing Cost Estimate (TRACE): A Field Survey, Systems and Cost Analysis Department, School of Logistics Science, U.S. Army Logistics Management Center, Fort Lee, VA, (#).
Assessment of experience in using and teaching TRACE techniques.

4. Lenox, H.T., MAJ USAF, Risk Assessment, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1973, (AD 767 871).
Includes Bayesian concepts.

5. Lilge, R.W., Total Risk Assessing Cost Estimate (TRACE): An Evaluation, U.S. Army Research and Development Command, Systems and Cost Analysis Division, St. Louis, MO, February 1979, (AD B034 709), (LD 44065A).
Discussion of experience in AVRADCOM; discusses techniques that could be used.

6. Lochry, R.R., COL USAF, et al, Final Report of the USAF Academy Risk Analysis Study Team, Deputy for Systems, Aeronautical Systems Division, Wright-Patterson AFB, OH, August 1971, (AD 729 223).
Comprehensive graphic displays. Methods of utilization are covered.

7. McNichols, G.R., "Generation of Parameter Values in Subjective Probability Density Functions", Management Consulting and Research, Inc., Falls Church, VA, March 1977, unpublished.

8. Williams, C., and Crawford, F., Analysis of Subjective Judgement Matrices, The RAND Corporation, Santa Monica, CA, 1980, (#).
Discusses an improved method for obtaining consistent judgement matrices from subjective estimates.

No AD/LD number identified.

OTHER TOPICS

	ACQUISITION PHASE				MANAGEMENT AREA						RISK VARIABLES			ANALYTICAL APPROACH						SOFTWARE
	CONCEPTUAL	R&D	T&E	PRODUCTION	BUDGETING	PLANNING	SCHEDULING	CONTROLLING	CONTRACT PRICING	ACQUISITION STRATEGY SELECTION	COST	SCHEDULE	TECHNICAL	NETWORK ANALYSIS	DECISION ANALYSIS	MONTE CARLO	RISK FACTOR	MOMENTS	OTHER	
1		X				X	X	X			X	X		X		X				MATHNET
2												X								
3														X	X	X	X			
4	X	X	X	X										X						VERT, RISCA, GERT
5		X			X	X								X		X	X			RISNET
6						X		X			X	X		X		X				
7		X			X	X					X							X		
8											X	X	X						X	

APPENDIX B

DEFINITION OF TERMS

Acquisition Environment - The totality of policies, practices, and practical considerations relative to management of acquisition programs.

Activity - A program element having extension in time and/or consuming resources

Arc - The line connecting two points in a network.

CER - Cost Estimating Relationship. An estimating relationship in which cost of a system is the mathematical result of a formula having selected system measurements (like thrust or weight) as values in the formula.

Coefficient of Variation - Ratio of standard deviation to expected value. (See Standard Deviation and Expected Value). A measure of relative uncertainty.

Confidence Interval - Limits of an uncertain quantity (like cost) between which there is a given probability of occurrence. Expressed as in "the *n* percent confidence interval". The confidence level is the left hand lower confidence interval, so that one may say, "C is the nth confidence level", meaning there is an *n* percent probability of cost being between 0 and C.

Confidence Level - Percentile

Consistent Judgement Matrix - A judgement matrix that expresses relationships like probabilities, so that if probability of I is m times that of J, and J is n times that of K, then the probability of I is mn times that of K. Since each entry is a ratio, r_{ij}, of the probability of I divided by the probability of J, then r_{ij} times r_{jk} equals r_{ik}.

Critical Path - A path with no slack.

Cumulative Distribution Function - A curve or mathematical expression which associates a probability to all values in the set of values over which it is defined, so that the probability is that of the occurrence of a value less than or equal to a given value.

Decision Analysis - Examination of decision problems by analysis of the outcomes of decision alternatives, the probabilities of arrival at those outcomes, and the intervening decisions between selection of alternatives and arrival at outcomes. The attributes of the outcomes are examined and numerically matched against preference criteria.

Decision Tree - Representation of a decision problem as paths from a present decision through alternative, intermediate decisions and risky events to outcomes. The representation is similar to an increasingly branched tree.

Engineering Change Order Allowance - A budget category to be used for funding changes in the physical or performance characteristics of a system.

Expected Value - The probabilistic average of an uncertain quantity. It equals the sum of all the products of each considered value times its corresponding probability. Also called the mean when applied to all possible values of the uncertain quantity.

Gantt Chart - A bar graph of horizontal bars showing program element commencement and termination against time.

Histogram - A vertical bar chart. A method often used to represent a Probability Mass Function (PMF).

Incentive Share Ratio - The ratio of government-to-contractor assumption of cost or saving related to contract target cost.

Independence (also statistical independence) - The relationship between two or more events when knowledge of the probability of occurrence of one does not alter the probability of another.

Judgement Matrix - A square array of values such that all entries are positive and for every entry in row i and column j there is an entry in row j and column i which is the reciprocal of the first.

Management Reserve - An amount of budget held aside from direct allocation to program elements as a reserve for contingencies.

Mode - A point on a probability density function where the probability goes from increasing to decreasing, that is, a maximum.

Model - A partial description of a system using sufficient detail for some analytic or descriptive purpose.

Moment - A function (called the expectation) of a probability law, often referred to as an "n^{th} moment", where $\underline{n}$ is any number and denotes an exponent on the uncertain quantity. For example, if $\underline{x}$ is a discrete uncertain quantity, the third moment is the sum of all values of $\underline{x}^3$ times the probability of each respective value of $\underline{x}$.

Monte Carlo - The simulation technique in which outcomes of events are determined by selecting random numbers subject to a defined probability law. If the random number falls within the limits of an outcome's probability, that outcome is chosen.

Multiplicative Cost Elements - Cost elements whose value is derived by a multiplication of other cost elements.

Network - A collection of points connected by lines.

Network Program Model - Representation of a program by means of a network in which the points (nodes) stand for program decision points or milestones and the lines (arcs) stand for program acti-

vities which extend over time and consume resources. Nodes may be regarded as activities requiring no time to complete.

Node - One of a collection of points defining a network.

Objective Probability - Probability which can be inferred from objective facts.

Odds - The ratio of probabilities of occurrence and non-occurrence; e.g., for a throw of a fair die the probability of a four is 1/6. The odds are (1/6) / (5/6) or (1/5).

Path - A sequence of arcs.

Percentile - The value of an uncertain quantity, generally referred to as an "n^{th} percentile", which is greater than or equal to n percent of all values.

PERT - Program Evaluation and Review Technique . An early network analysis technique for acquisition programs, in which each activity duration was characterized by its mean or expected values and no uncertainties were incorporated.

Probabilistic Event Analysis - Risk assessment, using a variation of the decision analysis method, developed in reference [54] of Appendix B, Bibliography, Basic Discussion.

Probability Density Function (PDF) - A probability expression such that the area under the function between defined limits of the values on which it is defined represents the probability of the values within those limits.

Probability Function - A mathematical expression, defined on an uncertain quantity, associating a probability with each value or non-redundant combination of values in the set.

Probability Mass Function (PMF) - A function assigning probabilities to each value of uncertain quantity having only discrete or discontinuous values.

Program Risk - The probability of not achieving a defined cost, schedule, or technical performance goal.

Random Number Generator - A computer program capable of providing numbers able to pass statistical tests indicating that any number between the limits of those generated is equally as likely to be generated.

Regression Analysis - Determination of the values of constants in a mathematical expression which gives results that are the closest to the observed values associated with values of the data used in the expression. For example, if cost C is assumed to be the sum of a fixed cost, F, and variable cost, V, for N items, C=F+VN. If data show the expression to be inexact, regression analysis finds values of F and V which give the value, C, closest to those associated with all data values of N.

Risk - The condition of having outcomes with known probabilities of occurrence, not certainty of occurrence.

Risk Assessment - Mathematical analysis of the probability of achieving or not achieving acquisition program cost, schedule, or performance goals.

Simulation - The operation of a model which provides outputs analogous to the system modeled.

Skew - The asymmetry of a probability density function. The skew is to the side of the mode under which lies the greatest area.

Skewness - The measure of the amount of skew.

Slack - The difference between the earliest possible completion time of a path or activity and its latest possible completion time.

Standard Deviation - The square root of the variance. Often used because it is in the same units as the random variable itself,

and can be depicted on the same axes as the PDF of which it is a characteristic

Standard Normal Function - A probability function centered on zero, with a standard deviation of 1, having a bell shape and covering values that become negatively and positively infinite.

Subjective Probability - An expression of predictability in terms of personal statements obeying the axioms of probability and equal to the probabilities acceptable to the assessor for a substitute gamble.

Uncertainty - The condition of having outcomes with unknown probabilities of occurrence.

Utility Theory - Theory of preference under conditions of risk.

Variance - A measure of the variability of a random variable. The standard deviation squared. Often symbolized as Var ( ).

Work Breakdown Structure - A hierarchy of engineering or functional elements required and defined by reference [15], Chapter VI.

APPENDIX C

ACRONYMS

ACAT	-	Acquisition Category
AD/LD	-	Document number prefix for documents from the Defense Technical Information Center and the Defense Logistics Information Exchange (respectively)
AFSARC	-	Air Force Systems Acquisition Review Council
AFSC	-	Air Force Systems Command
ARB	-	Acquisition Review Board
ASARC	-	Army Systems Acquisition Review Committee
BCE	-	Baseline Cost Estimate
CDF	-	Cumulative Distribution Function
CDR	-	Commander
CER	-	Cost Estimating Relationship
DA	-	Department of the Army
DARCOM	-	U.S. Army Development and Readiness Command
DCP	-	Decision Coordinating Paper
DCSRDA	-	Deputy Chief of Staff for Research, Development, and Acquisition
DOD	-	Department of Defense
DPESO	-	Defense Product Engineering Services Office
DRA	-	Decision Risk Analysis
DSARC	-	Defense Systems Acquisition Review Council
DT	-	Development Test
EDT	-	Engineering Development Test
HQDA	-	Headquarters, Department of the Army
ICA	-	Independent Cost Analysis
IE	-	Independent Estimate
ILS	-	Integrated Logistics Support
IPR	-	In Process Review
ISR	-	Independent Schedule Review
LOI	-	Letter of Instruction
MICOM	-	U.S. Army Missile Command
MR	-	Management Reserve
MR	-	Materiel Readiness
NAVAIR	-	Naval Air Systems Command
NAVELEX	-	Naval Electronic Systems Command
NAVMAT	-	Naval Material Command
NAVSEA	-	Naval Sea Systems Command
NSARC	-	Navy Systems Acquisition Review Council
OMB	-	Office of Management and Budget
OPEVAL	-	Operational Evaluation
OSD	-	Office of the Secretary of Defense
OT	-	Operational Test
PDF	-	Probability Density Function
PEA	-	Probabilistic Event Analysis
PERT	-	Program Evaluation and Review Technique
PM	-	Program Manager

PMD	-	Program Management Directive
PMF	-	Probability Mass Function
PMO	-	Program Management Office
POM	-	Program Objectives Memorandum
PRR	-	Production Readiness Review
R&D	-	Research and Development
RA	-	Risk Analysis
RCE	-	Risk Cost Estimate
RFM	-	Requiring Financial Manager
SCP	-	System Concept Paper
SSA	-	Source Selection Authority
SSAC	-	Source Selection Advisory Council
STOG	-	Science and Technology Objectives Guide
T&E	-	Test and Evaluation
TECHEVAL	-	Technical Evaluation
TRACE	-	Total Risk Assessing Cost Estimate
TRACE-P	-	Total Risk Assessing Cost Estimate for Production
USA	-	U.S. Army
USAF	-	U.S. Air Force
USN	-	U.S. Navy
WBS	-	Work Breakdown Structure

APPENDIX D

QUANTIFYING EXPERT OPINION

1. GENERAL

All of the risk assessment methods share a common sensitive aspect -- that of acquiring quantitative expressions of expert's uncertainty that violate neither their own beliefs (are consistent) nor the axioms of probability.

By "not violating the axioms of probability" is meant that the probabilities of all possible events must sum to one, that the probability of any event must be a number between zero and one, that the impossible event has a probability of zero, and that the probabiltiy of joint events is the product of the probability that one event occurs and the probability that the other occurs, given that the first has occurred. When the probability that joint events occur is simply the product of the probability of each, they are said to be independent. (See Appendix E for more on independence).

Although these ideas are not complex, when people must answer detailed questions about probability, an analyst often finds that even mathematically sophisticated experts violate one or more of the principles. In order to forestall misstatements the analyst should be familiar with a number of techniques of obtaining subjective probability estimates. The literature of decision analysis has paid particular attention to these problems and techniques, and the reader can find interesting discussions in [2], [3], [4], and [10].

Figure D-1 taken from [3] helps to illustrate the need for subjecting uncertain beliefs to the discipline of quantification. Figure D-1 shows the results of what 23 military experts meant by the phrases shown on the left side of the diagram. All the

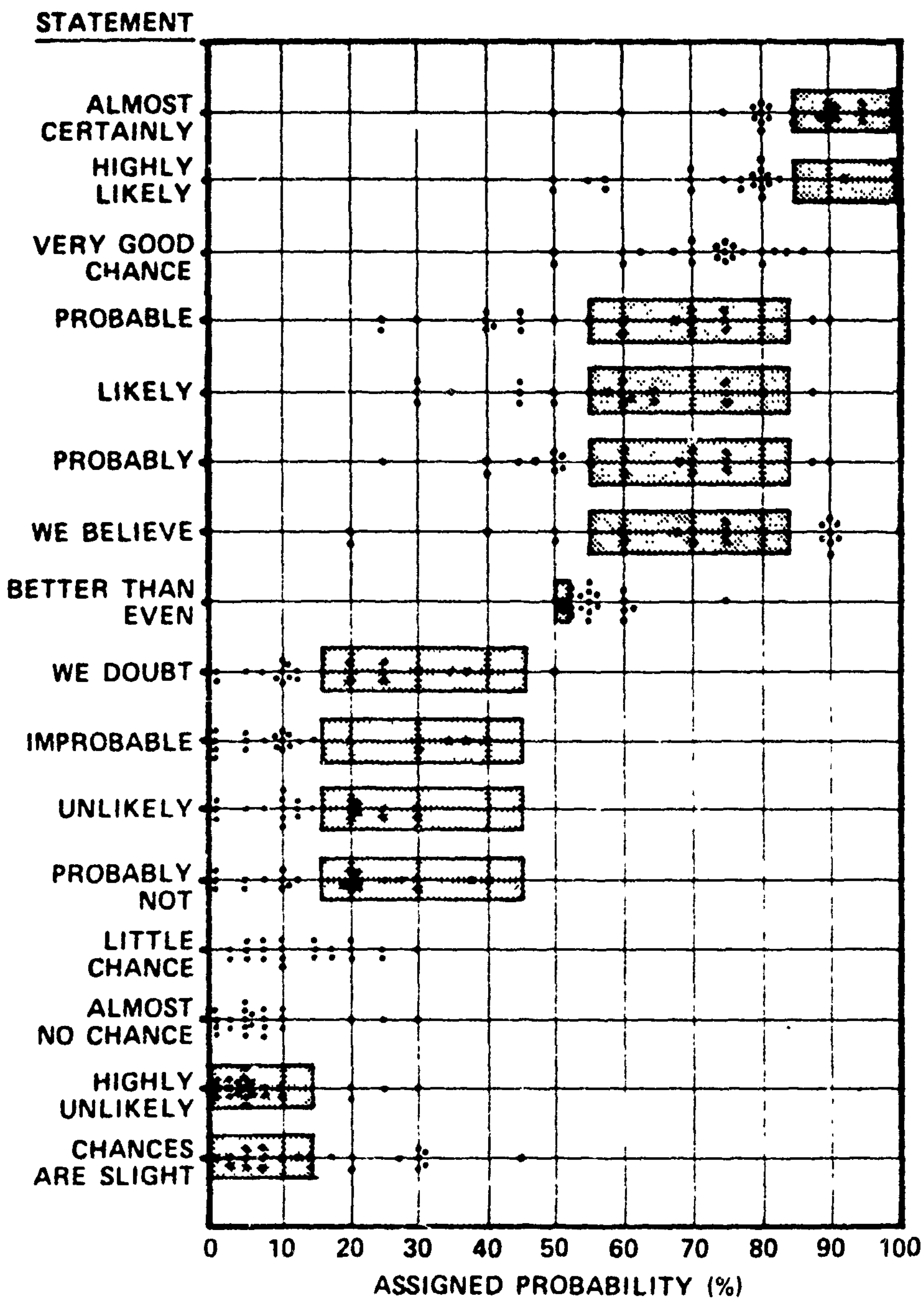


Figure D-1

WHAT UNCERTAINTY STATEMENTS MEAN TO DIFFERENT READERS

experts were professionally familiar with the military intelligence context in which these expressions were used, yet their interpretations in quantitative terms ranged over the values shown where the dots appear. (The dark bars represent a researcher's recommendations for standardizations). Examples from other sources show similar variation in intended meanings.

The diagram illustrates the need for a common language in uncertain situations; but how can the analyst undertake to provide this common language? No single method has been found to be completely reliable, but a number of different methods exist. The use of two or more methods often serves to detect errors and inconsistencies which can then be examined and resolved.

2. DIRECT METHODS

A first approach to obtaining subjective probability distributions is the direct one of requesting the estimate of a probability to be assigned to each value of a range of values. The method's mirror image is that of requesting the assignment of a value to a selected number of probability levels, such as zero, 25 percent, 50 percent, 75 percent, and 100 percent. The difficulty with these approaches is that they are likely to produce results that are intuitively unappealing. Because of the way the questions are phrased and because of the confusion likely to exist in a respondent's mind, the result is likely to be inconsistent or to violate probability axioms. Figure D-2 is an example in which total probability exceeds one.

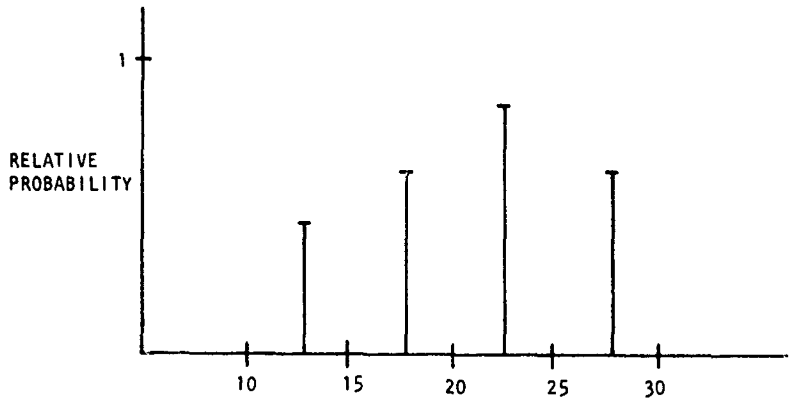


Figure D-2

INCONSISTENT ASSESSED PROBABILITY

In a second method, the analyst requests a lowest possible value, a most likely value, and a highest possible value, and either makes an assumption about density function forms or asks his expert to pick a form from an illustrated collection. A difficulty that sometimes occurs with this method is that experts have at times been unwilling to estimate a range of numbers or anything other than a single number. Some analysts have found some respondents willing to estimate a number at which p percent (where p might equal 10, or 5, or 1) of the values will be less than, more than, (for the high end), or equal to the given number, as in Figure D-3 where 1% is used.

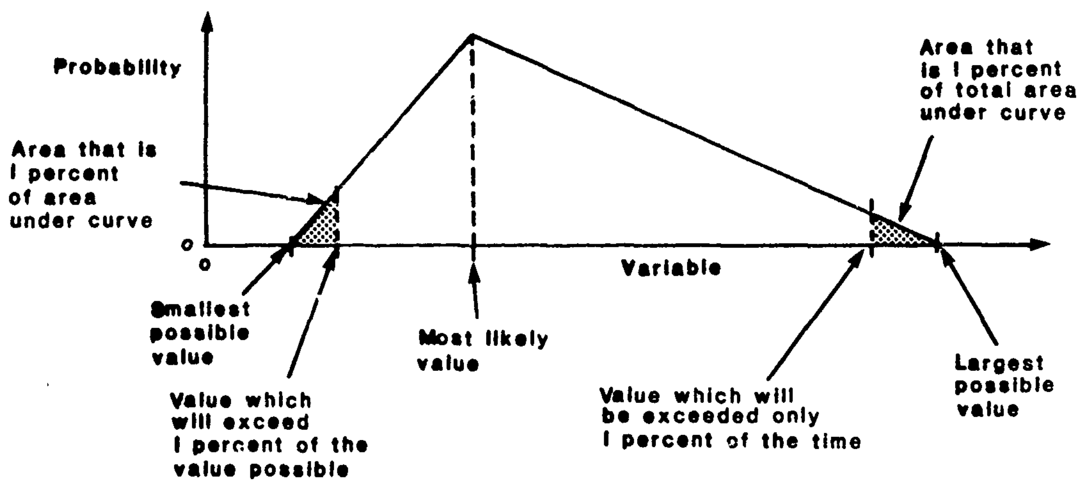


Figure D-3

PDF CORRESPONDING TO A THREE-VALUE ESTIMATE

In many cases, for many distributions, the latter procedure can imply the information the expert was unwilling to give directly. Either of these three-value methods may be adequate for communicating uncertainty about which the expert respondent has a hazy notion. There are, however, methods available that are more exact, although they require more effort. Some of these methods are discussed below.

3. THE MODIFIED CHURCHMAN-ACKOFF METHOD

In this method, discussed in [2], the expert is asked to define a set of "events" that describe the outcomes of some "experiment". For example, let us say the experiment is the development of a WBS element and the events are the costs of development. The expert must define a set of events that is exclusive (they do not overlap) and exhaustive (all outcomes are covered); e.g., costs from 10 to 15, from 15.01 to 20, from 20.01 to 25, and from 25.01 to 30.

This set of events is exhaustive; there can be no outcome below 15 or greater than 30. It is exclusive because no event overlaps any other--if one event had been 20 to 23 and another 23 to 25, they would not have been exclusive.

Having defined a set of events, the expert must next put them in order of likelihood. For example, his ordering might be 20 to 25, 25.01 to 30, 15.01 to 20, and 10.01 to 15. If any are of equal likelihood, that must be stated.

Next, the expert is asked to compare each event against each other event and to state which is the most likely. At this point the analyst should graph these estimated relative magnitudes as in Figure D-4. The redundant exercises are carried out in order to detect both inconsistencies and equalities. After doing this, the events are again ranked, this time by frequency of being the more likely of each pair. The two rankings may not be the same, and if not, the expert should be asked to decide which ranking he prefers.

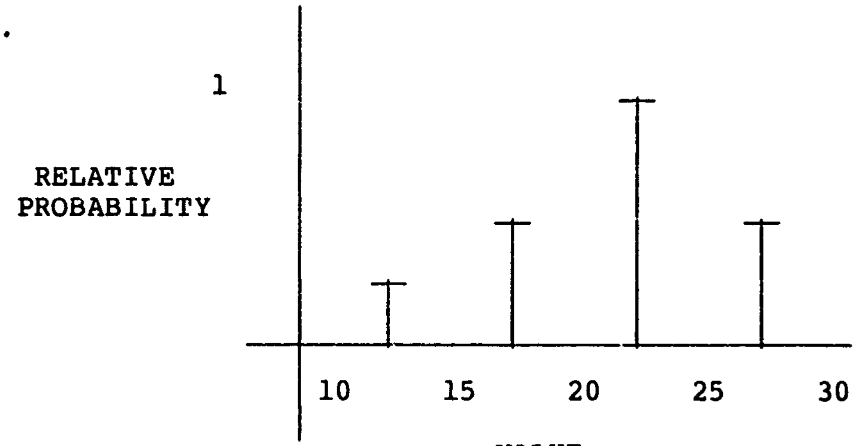


Figure D-4

RELATIVE RANKING OF EVENT PROBABILITIES

After an acceptable ranking has been obtained, the expert should be asked to provide ratios of the event pair likelihoods. In other words, he is asked to say things like, "event one is two-thirds as likely as event four", where event one may be 15.01-to-20, and four may be 20.01-to-25. He must do this for every pair of events. By assigning an arbitrary value to any one of the events, the sum of values of all of the events can then be set to equal one. By using the ratio of the value of each event to the sum of the values of all events, the analyst has a subjective probability for each.

4. THE NORMALIZED GEOMETRIC MEAN VECTOR METHOD

Experts (and laymen) find it difficult to assign consistent likelihood ratios (or odds) to event-pairs. Not infrequently, if there are a large number of event-pairs, some combination of events will have a likelihood with which the providing expert does not agree, even through the likelihood was derived from his ratio statements. The authors of [14] have devised a method to determine the assignment of individual event probabilities which corresponds most closely to the event pair statements, yet fulfills the requirements of the axioms of probability.

For example, if there are five events under consideration, one can speak of the likelihood ratios of events 1-2, 1-3, 1-4, and 1-5, plus the ratios of events 2-3, 2-4, and 2-5, plus those of events 3-4 and 3-5, plus the ratio of events 4-5. Ratios of the likelihood of each event to that of itself are 1, and if there is a ratio n-m, then there is a ration m-n. These features make a matrix a natural way to display this information, as in Figure D-5.

EVENTS	1	2	3	4	5
1	1	a_{12}	a_{13}	a_{14}	a_{15}
2	$1/a_{12}$	1	a_{23}	a_{24}	a_{25}
3	$1/a_{13}$	$1/a_{23}$	1		$\vdots$
4	$1/a_{14}$			1	
5	$1/a_{15}$	...			1

Figure D-5

JUDGMENT MATRIX

Such a figure meets the criteria of a so-called "judgment-matrix" in that the entry in position i,j is the reciprocal of the entry in position j,i and all entries are positive. A judgment matrix is said to be "consistent" if its entries can be multiplied so that entry i,j times entry j,k gives entry i,k.

The method of [14] permits taking an <u>inconsistent</u> judgment matrix and deriving from it a set of probabilities from which the closest <u>consistent</u> judgment matrix can be constructed. The reader who wishes to know what "closest" means is referred to [14]. It turns out that the probability assignment that does the job is the normalized geometric mean of each row; that is, if the matrix compares the likelihoods of <u>n</u> events against one another and there is therefore an <u>n</u> by <u>n</u> sized matrix, the probability of

each event can be found by finding the product of the ratios in that event's row, finding the n^{th} root of that product, and dividing by the sum of all $\underline{n}$ such product roots.

To illustrate, take the following matrix as representing the assessed likelihood ratios of three events.

Event	1	2	3
1	1	1/2	1/3
2	2	1	3/4
3	3	4/3	1

Figure D-6

EXAMPLE JUDGMENT MATRIX

Now the matrix is a judgment matrix, but it is not consistent. A set of probabilties that will yield a consistent matrix--one that will represent a better set of subjective probabilities--can be found by the following operations:

$$
\begin{array}{lcr}
\text{Row 1} \quad (1 \times 1/2 \times 1/3)^{1/3} & = & 0.5503 \\
\text{Row 2} \quad (2 \times 1 \times 3/4)^{1/3} & = & 1.1447 \\
\text{Row 3} \quad (3 \times 3/4 \times 1)^{1/3} & = & \underline{1.5874} \\
\text{Total} & & 3.2824
\end{array}
$$

$$
\begin{array}{lcr}
P[E_1] = .5503/3.2824 & = & 0.1677 \\
P[E_2] = 1.1447/3.2824 & = & 0.3487 \\
P[E_3] = 1.5874/3.2824 & = & 0.4836
\end{array}
$$

These probabilities will give a consistent judgement matrix as close to the original as possible, as shown in Figure D-7;

Event	1	2	3
1	1	.1677/.3487	.1677/.4836
2	.3487/.1677	1	.3487/.4836
3	.4836/.1677	.4836/.3487	1

Figure D-7

CORRECTED JUDGMENT MATRIX

or, carrying out the divisions, Figure D-8.

Event	1	2	3
1	1	.4809	.3468
2	2.0793	1	.7211
3	2.8837	1.3869	1

Figure D-8

FINAL JUDGMENT MATRIX

Comparing Figure D-8 with Figure D-6 shows how close it is, in a sense, and also how difficult it would have been to arrive at a consistent set of probabilities by trial-and-error.

The Modified Churchman-Ackoff method and the Normalized Geometric Mean method will give the same answers for a consistent judgment matrix. It may be very difficult to obtain probabilities resulting in a consistent matrix by direct questioning, and therefore, by use of the Modified Churchman-Ackoff method. A reasonable approach to take in such as case would be to apply the method of Normalized Geometric Means to obtain a probability distribution and then to see if the expert cannot accept it. It is possible that he will feel his ability to describe his own uncertainty is so imprecise that he can accept the consistent distribution; i.e., it is close enough.

5. GAMBLE METHODS

One of the difficulties inherent in either of the two foregoing methods is that, as the number of relevant events increases, so does the difficulty of directly assigning probabilities or ratios of probabilities. For example, had the events in these previous examples been defined as $1.00 intervals, the number of events would have been too great to evaluate probability ratios meaningfully. What is to be done, then, when the

number of relevant events is very large? Fortunately, other methods can be used, and some are discussed in the following sections:

a. <u>Choice Between Gambles for Probability Density Functions (CBG/PDF)</u>.

Many people, when questioned one way, are likely to make probability statements that are inconsistent with what they will say when questioned in another way, especially if they are asked for direct assignment of probabilities.

One method of phrasing questions, covered in [2] and [4], that helps avoid inconsistency states the problem in terms of betting gambles. In this context the analyst will ask the expert to consider two situations, one in which the ucertain event will occur or not, and the other in which the expert will participate in betting on a game of chance. In the case of the given event, the expert is told he will receive a valuable prize if the event occurs. In the case of the game of chance, he will receive the same prize if he wins. He is asked to name the odds (or probability) that he would accept in the game of chance to make him indifferent between playing the game or receiving his prize in the case of the event's occurrence.

To complete a probability density function (or a histogram), the analyst repeats this procedure for a convenient number of events over the range of the uncertain quantity (e.g., cost). In the case of the histogram (Probability Mass Function) he is finished. For a PDF he plots the points determined at the center of the range of each event and smooths in a curve, so that the area under it equals 1, as in Figure D-9. The analyst must also ensure that all the probability theory requirements are met (see paragraph 1 for those requirements). If they are not met, questions must be reformulated, or numbers revised by normalization, or some combination.

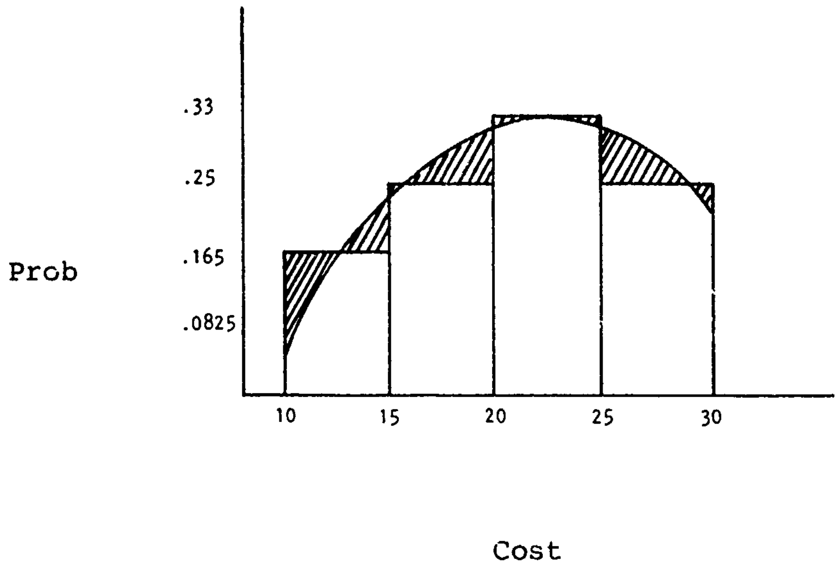


Figure D-9

HISTOGRAM AND APPROXIMATE

DENSITY FUNCTION

A variant of this method uses a physical analogy rather than simply a statement of odds or probability. This is called the Standard Lottery Method. The analogy used may be an urn with a number of black balls and a number of white balls, the sum of the two colors totaling 100. The probabiltiy is determined when the ratio of black to white balls is such that the expert is indifferent between receiving the prize either for drawing the right colored ball or for occurrence of the event.

Another analogy is the dial with the spinning arrow. The expert is asked to draw the sector of the dial which would make him indifferent to receiving the prize either for the arrow's stopping within his chosen sector or for the occurrence of the event. The ratio of the length of the sector's edge to the full circle's circumference is the probability.

The last analogy is for the expert to name the number of lottery tickets he would have to be given (each ticket equally likely to win) out of a total number for him to be indifferent between receiving the prize either from winning the lottery drawing or from the occurrence of the event.

b. Choice Between Gambles for Cumulative Distribution Functions (CBG/CDF).

In this method, shown in [2] and [4], the analyst holds the probabilities fixed and varies the size of the event being evaluated. In order to do this, the analyst asks the expert to name a point on the range of the uncertain quantities at which he would be indifferent between receiving a prize for the true value to fall in the lower (or upper) partial range and receiving a prize for correctly calling a fair coin-toss.

Another way of putting the question is to ask the expert to name a value such that the true value is as likely to be less as to be more than the value he names. How this information is converted to usable values will be explained in the next few paragraphs.

The next step in this procedure is to ask the expert to name a value in the lower (or upper) partial range at which he is equally as willing to be awarded the prize for the true value to be below that named value (and not in the range between the named value and that named in the first step) or for correctly calling a fair coin-toss.

The following steps repeat this process as many times as are convenient in order to obtain enough points to draw a reasonably smooth curve. Usually no fewer than three internal points are required, plus two extreme points. The extreme point at the low end represent the highest point the expert can name which he feels certain will not ever exceed the true value. The extreme point at the high end represents the least value he can name which he is certain the true value can never exceed.

The product of the CBG/CDF is a cumulative distribution function similar to Figure D-10.

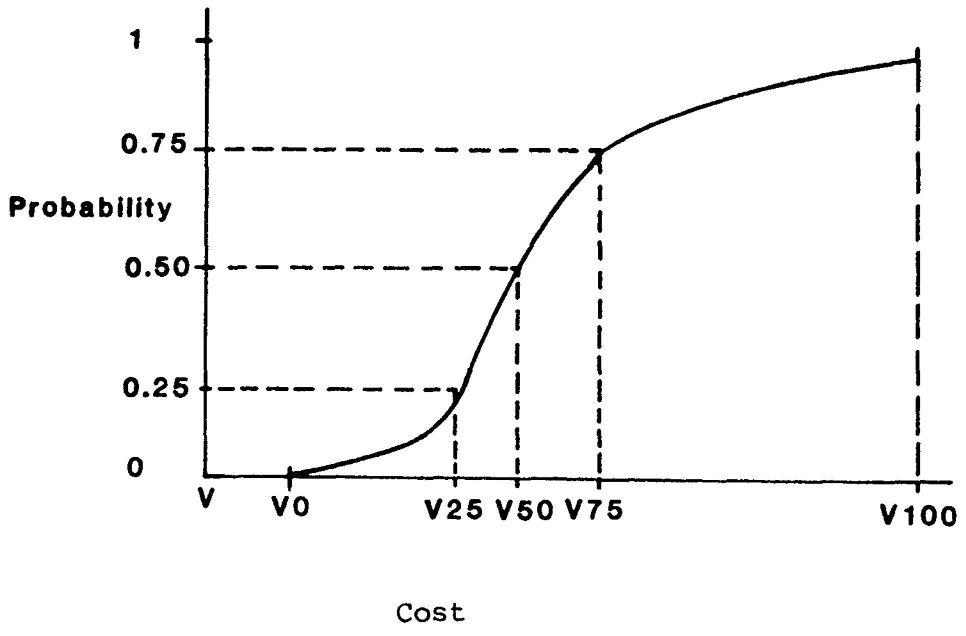


Figure D-10

CUMULATIVE DISTRIBUTION FUNCTION

Before the analyst produces the CDF, he will find it convenient to use an interval plot, such as Figure D-11, as a working tool. The following approach is adapted from [4]. Figure D-11, Line (a), shows how the interval plot would look upon starting. The first step would establish a cost value which we will call V_{50}. We plot it as in Line (b). The second step establishes the point where the expert believes there is as much chance in the true value's lying to its left as there is in its lying to the right, but below V_{50}, as in Line (c). This point is called V_{25}.

The point, V_{75}, shown in Line (d), is similarly found. Line (e) finishes the working plot with V_0 and V_{100}. Each of the points determined represents an endpoint to an interval within which an equal probability is "spread". From this interval plot we make a CDF by starting the curve on the horizontal axis at V_0, putting a point at a height of 0.25 at V_{25}, another at a height of 0.50 at V_{50}, and so forth. The method of breaking up intervals produces a CDF; i.e., a curve that means the true value of the uncertain cost has the stated probability of being less than or equal to the value corresponding to the probability.

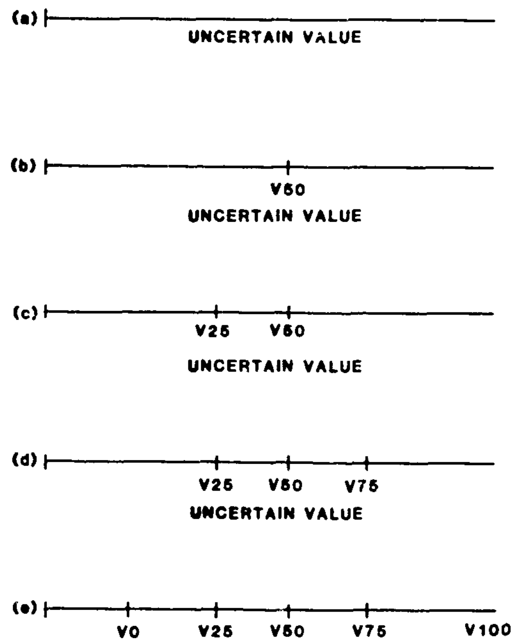


Figure D-11

INTERVAL PLOTS

From this CDF the analyst can draw a Probability Density Function (PDF) to check it for inconsistency with the expert's true belief. He does this in the following way.

Suppose the values in the CDF in Figure D-10 are the following:

$V_0 = 10$
$V_{25} = 30$
$V_{50} = 37$
$V_{75} = 48$
$V_{100} = 85$

Divide the curve into segments in which the slope can be closely approximated by straight lines. Divide the vertical height of each segment by the horizontal lengtn of the segment. Plot the results at points at the midpoints of the horizontal segments. Smooth in the points. Figure D-11 results from using this procedure with Figure D-12, and is typical of such approxi-

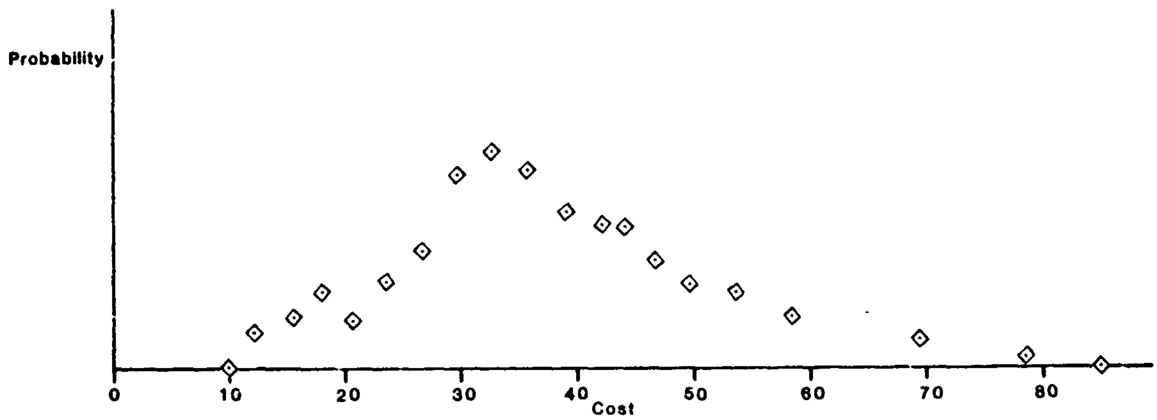


Figure D-12
PDF CONSTRUCTED FROM SUBJECTIVE CDF

mate PDF's. It does not look as smooth as a classical PDF of probability theory and it probably does not contain an area of 1 under it, but it gives a fair idea of the implications of the expert's statements. If the PDF showed a "lumpier" profile the analyst might suspect inconsistency and ask the expert to confirm

or modify his statements. The analyst also might, in this case, draw a triangular or other classical distributional and ask the expert whether or not he could accept it as an approximation. Making this change would permit much more convenient mathematical manipulation.

The triangular distribution shown in Figure D-13 results from fitting a triangle to V_0, V_{100} and the high point located in the same place as that in Figure D-12. A CDF derived from the triangular PDF differs from the original (as shown in Figure D-14) by amounts that might be considered unacceptable, so the fitting of a triangle may be inappropriate.

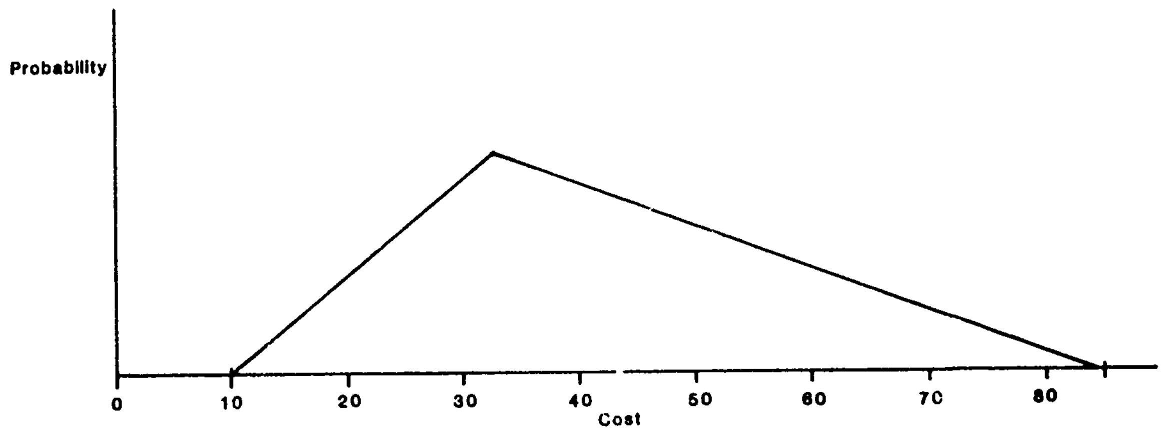


Figure D-13
TRIANGULAR PDF BASED ON SUBJECTIVE CDF

Another, more complex distribution like that in Figure D-15 having the same lower and upper limits and high point location may be considered more appropriate. This curve fitting may be accomplished by the methods of [11].

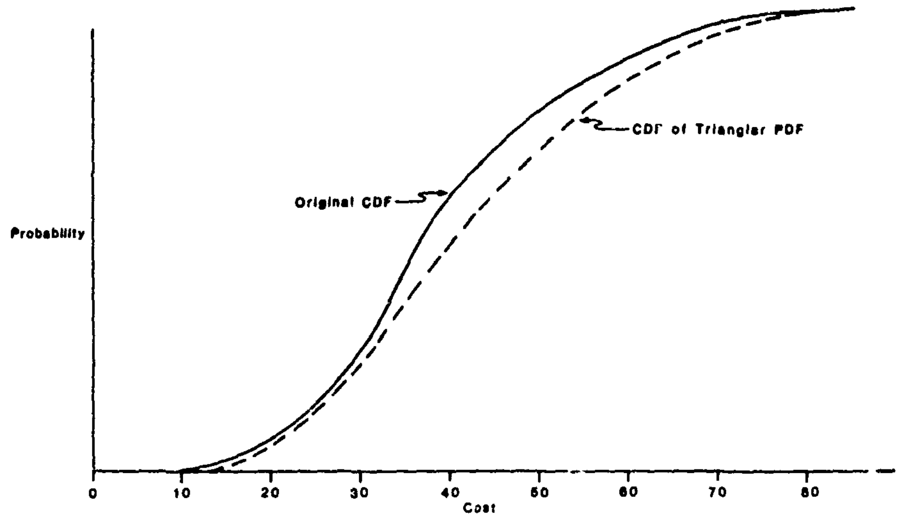


Figure D-14
CDF's COMPARED

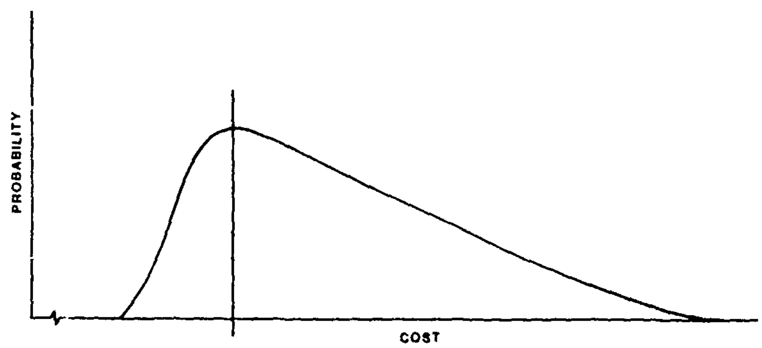


Figure D-15
MATHEMATICALLY COMPLEX PDF

6. DIAGRAMMATIC METHODS

Many analysts (e.g., [5], [6], [9], [11]) feel that a quicker and more accurate way of describing an expert's uncertainty is that of presenting him with a range (as many as 20) of PDF diagrams so that he can identify a general shape. By doing this, he is able to show that his strongest belief is either centered

or near an extreme (the PDF is symmetric or skewed, respectively), that there are or are not limits to the value (the PDF hits or does not hit the horizontal axis), or that he is quite or not very uncertain (the PDF has a large or small relative spread). Having identified a PDF shape, the expert then supplies his estimates of most likely and extreme values. The extreme values can either be absolute, for those situations in which the PDF hits the horizontal axis, or percentile values, for kinds where it does or does not hit.

The attractiveness of the diagrammatic method is its seeming ease of application. Problems can arise, however, when the expert is not relatively familiar with probability concepts. For example, maybe his true PDF simply is not like any of those shown, then one of the other, previous methods must be used.

Summary. None of the methods just discussed is foolproof. None should be the sole method used. The analyst should search for inconsistencies and try to reconcile them. Some analysts take a rather perfunctory attitude toward the risk assessment area involved with describing the elemental uncertainties, but it should be realized that a risk assessment describes people's judgements, and people's judgements are complex. A risk assessment performed without the exercise of care in obtaining its basic inputs can be properly criticized.

7. GROUP ASSESSMENTS

In matters of great criticality, the manager may not be satisfied to consult a single expert on some element of a risk assessment. He may feel that there is no single completely authoritative person, but that three or more should contribute assessments. This sounds fine, but what does he do with three experts who disagree? He can do such things as averaging or weighted averaging, but there seems to be no persuasive argument for so doing.

Committee approaches to obtaining a group assessment have been found to incorporate problems relating to interpersonal pressures to a degree that caused researchers at the RAND Corporation to devise a method avoiding those pressures, the Delphi technique [7].

The Delphi technique has become well-known in management circles, but is subject to misconception. Too often the term is used to identify a committee or multiple-interview process, and these do not share the advantages of the technique.

The Delphi technique differs from other methods of obtaining a group opinion in its keeping the group's members apart from one another in order to reduce irrelevant interpersonal influences. Properly carried out, the technique is facilitated by a moderator's obtaining each panel member's opinion (using, for example, the methods cited above) and each member's reasons for his opinion. The moderator then reduces the opinions and reasons to standard statements to preserve anonymity and shows the panel member the aggregated opinions of the other panel members in statistical terms. He provides each panel member with the reasons justifying the opinions that differ with his, and requests a re-evaluation and more substantiation. This iterative feeding back continues until no further substantial change results. At this point, the moderator takes the final individual opinions and computes a set of median values to represent the group opinion. The median value, rather than the average, is used as a central estimate to prevent the estimate from being overly influenced by extreme individual values.

The Delphi technique is time consuming, but there seems to be no other which averts the dangers inherent in other group response methods.

LIST OF REFERENCES

1. Antunes, Moore, Ed., Army Programs Decision Risk Analysis (DRA) Handbook, U.S. Army Logistics Management Center, Fort Lee, VA (DARCOM Handbook 11-1.1-79), 1979, (#)

2. Atzinger, E. et al, Compendium on Risk Analysis Techniques, DARCOM Material Systems Analysis Activity, Aberdeen Proving Ground, MD, 1972, (AD 746245), LD 28463).

3. Barclay, Brown, Kelly, Peterson, Phillips, and Selvidge, Handbook for Decision Analysis, Decisions and Designs Inc., McLean, VA, 1977, (#).

4. Brown, R.V., Kahr, A.S., and Peterson, C., Decision Analysis for the Manager, Halt, Rinehart & Winston, New York, NY, 1974, (#).

5. Cost Uncertainty/Management Reserve Analysis, Cost Management and Technology Division, Directorate of Cost Analysis, Deputy for Comptroller, Armament Division, Eglin AFB, FL, January 1982, (#).

6. Cost Uncertainty/Risk Analysis, Headquarters Air Force Systems Command, Andrews AFB, MD, June 1981, (#).

7. Dalkey, N., The Delphi Method: An Experimental Study of Group Opinion, Rm 5888-PR, The RAND Corporation, Santa Monica, CA, 1968 (#).

8. Dienemann, P., Estimating Cost Uncertainty Using Monte Carlo Techniques, the RAND Corporation, Santa Monica, CA. Jan 1966, (AD 629082).

9. Jordan, H.R., and Klein, M.R., An Application of Subjective Probabilities to the Problem of Uncertainty in Cost Analysis, Office of the Chief of Naval Operation, Resource Analysis Group (OP-96D), Pentagon, Washington, D.C., Nov. 1975, (ADA 105780).

10. Keeney, R.L., and Raiffa, H., Decisions with Multiple Objectives: Preferences and Value Tradeoffs, John Wiley & Sons, New York, NY, 1976, (#).

11. McNichols, G.R., On the Treatment of Uncertainty in Parametric Costing, The School of Engineering and Applied Science, The George Washington University, Washington, D.C., February 1976, (#).

12. Wilder, J.J., and Black, R., "Using Moments in Cost Risk Analysis", in Martin, Rowe, Sherman, Ed., Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs, University of Southern California, Colorado Springs,CO, 1981,(#).

13. Wilder, J.J., and Black, R., "Determining Cost Uncertainty in Bottoms-Up Estimating", Paper presented at the 1982 Federal Acquisition Research Symposium, The George Washington University, Washington, D.C., May 1982 (#).

14. Williams, C. and Crawford, G., Analysis of Subjective Judgment Matrices, The RAND Corporation, Santa Monica, CA, 1980. (#).

15. Worm, G.H., Application of Risk Analysis in the Acquisition of Major Weapon Systems, Clemson University, Department of Mathematical Sciences, Clemson, SC, 1980, (LD 49124A).

APPENDIX E

STATISTICAL INDEPENDENCE

A general difficulty in determining uncertain values that are functions of other uncertain values, as labor costs may be products of wage rates and hours, is the need for probabilistic independence of the input uncertain values. Probability theory makes computations relatively straightforward when inputs are probabilistically independent; that is, when knowledge of the probability of any uncertain value does not provide information about the probability of another. When the analyst can choose the elements of his mathematical model so that they are considered probabilistically independent, he can be more assured that he knows how to handle his model.

Much work has been done with models constrained to consider only probabilistically independent inputs, but the actual systems being modeled do not always behave in such a simple fashion. It is preferable, therefore, not to be limited to the use of independent inputs.

To illustrate this, consider the following example. It is expected that engineering labor wage rates will rise. Is it reasonable to say that this knowledge gives no information on the likely behavior of other wage rates? Certainly some correlation exists, and inputs relating to those matters cannot be strictly independent.

Usually an analyst who wishes to account for dependence will try to use an aggregation of all of the model elements which are not independent, so that the aggregate itself is independent of all the other elements. The aggregated values collectively become a single separate and independent element.

Other ways the problem of dependence can be overcome to a useful degree are suggested in [3] for simulation assessments and

in [10] and [13] for the method of moments. The two method-of-moments approaches are briefly described in Appendix F. While more complex and more exact methods of injecting dependence into simulations (i.e., network assessments and WBS simulations) are available, they will not be discussed herein.

LIST OF REFERENCES

1. Atzinger, E. et al, Compendium on Risk Analysis Techniques, DARCOM Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, 1972, (AD 746245), (LD 28463).

2. Cost Uncertainty/Management Reserve Analysis, Cost Management and Technology Division, Directorate of Cost Analysis, Deputy for Comptroller, Armament Division, Eglin AFB, FL, January 1982, (#).

3. Cost Uncertainty/Risk Analysis, Headquarters Air Force Systems Command, Andrews AFB, MD, June 1981, (#).

4. Dienemann, P., Estimating Cost Uncertainty Using Monte Carlo Techniques, The RAND Corporation, Santa Monica, CA. January 1966, (AD 629082).

5. Jordan, H.R., and Klein, M.R., An Application of Subjective Probabilities to the Problem of Uncertainty in Cost Analysis, Office of the Chief of Naval Operation, Resource Analysis Group (OP-96D), Pentagon, Washington, D.C., November 1975, (ADA 105780)

6. Kraemer, G.T., "Quick and Effective Risk Analysis", Transaction of the AACE Annual Meeting, 21st, pg.177; Morgantown, WV, 1977, (#).

7. McNichols, G.R., On the Treatment of Uncertainty in Parametric Costing, The School of Engineering and Applied Science, The George Washington University, Washington, D.C., February 1976, (#).

8. Moeller, G.L., Venture Evaluation and Review Technique, Decision Models Directorate, U.S. Army Armament Material Readiness Command, Rock Island, IL, November 1979, (AD A076 600).

9. Wilder, J.J., and Black, R., "Using Moments in Cost Risk Analysis," in Martin, Rowe, Sherman, Ed., Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs, University of Southern California, Colorado Springs, CO, 1981, (#).

10. Wilder, J.J., and Black, R., "Determining Cost Uncertainty in Bottoms-Up Estimating", Paper presented at the 1982 Federal Acquisition Research Symposium, The George Washington University, Washington, D.C., May 1982 (#).

11. Williams, J.B., CAPT USAF, An Analysis of Risk Assessment Within Aeronautical Systems Division, The School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1971, (LD 27458).

12. Worm, G.H., Application of Risk Analysis in the Acquisition of Major Weapon Systems, Clemson University, Department of Mathematical Sciences, Clemson, SC, 1980, (LD 49124A).

13. Worm, G.H., Applied Risk Analysis with Dependence Among Cost Components, Clemson University, Clemson, S.C. November 1981 (ADA 119 617).

APPENDIX F

TECHNIQUE DESCRIPTIONS

1. GENERAL

This Appendix examines each of the techniques introduced in Chapter IV in greater detail. The goal is for the reader to acquire an appreciation of the most important considerations in accomplishing assessments by use of each individual technique, however the reader wishing to embark on an assessment will need to pursue the subject in the references for the specific techniques.

2. NETWORK METHODS

a. Introduction

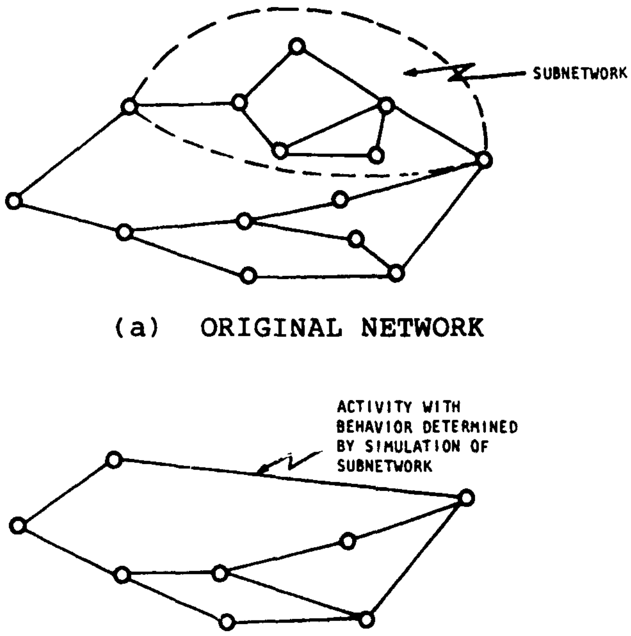
The reader who is not familiar with networks and the terms PERT, critical path, arc, and node should refer to any of the excellent introductory works on operations research such as [11] and to the List of Terms, Appendix B.

b. The Model

In general, networks like Figure F-1 consist of arcs (lines) and nodes (end points), the arcs being symbols for program activities and the nodes being symbols for decision points at the initiation or completion of the activities. Nodes are of three types: source (or originating) nodes, indicating the initiation of the program; intermediate nodes, indicating milestones or the initiation and termination of activities; and terminal nodes, representing the completion of the program or the failure to complete some segment of the program. Other means of organizing networks exist but will not be discussed here.

An awkwardly large comprehensive network can be partitioned into "sub-networks" when computer space or presentation purposes

dictate. Figure F-1 shows such a partition and the resulting simplified network. For example, when a comprehensive network is too large, it is sometimes possible to run sub-networks independently and to use the derived data as descriptors of arcs in a simplified network that substitutes for the original sub-network.



(b) RESULTANT EQUIVALENT NETWORK

Figure F-1

USE OF SUBNETWORKS

While these characteristics are common to most network project models, the techniques with which we are particularly concerned must use "stochastic" (probabilistic) network techniques. All of the network modeling computer programs cited in this handbook are designed to model probabilistic networks. In a probabilistic network there are two ways in which uncertainty manifests itself. First, activities may have uncertain outcomes in terms of time to complete, cost to complete, or achievement of one or more technical performance levels. Second, the initiation of activities emanating from a node may be predictable only in a probabilistic way. For example, a test outcome (pass/fail) may

determine whether the next activity is a progressive continuation of the plan or a corrective action. Since the test outcome cannot be predicted with certainty, it assumes a probabilistic nature. The network model represents this by showing at least two arcs emanating from the node representing test activity completion. The analyst assigns each arc some probability of being selected, depending on the information he has collected from experts. Likewise, he assigns probabilities to the appropriate arcs to represent the relevant probabilities of completing within time or cost constraints or of meeting performance levels.

An important aspect of network models that is needed to permit realistic simulation of programs is varied "node logic". "Node logic" refers to the rules which determine when, for example, a decision point is passed and when it initiates the subsequent activity.

The more advanced computer programs will allow use of both "AND" and "OR" input node logic and "DETERMINISTIC" and "PROBABILISTIC" output node logic. The two types of input logic determine whether all (in "AND" logic) or only one (in exclusive "OR" logic) or some (in "OR" logic) of the possible arcs entering a node must be completed for the node to be actuated. The two output logics determine whether all (in "DETERMINISTIC" logic) or only one (in "PROBABILISTIC" logic) arc (selected at random according to the input probabilities) is initiated upon completion of node actuation. Although later versions of network analyzers elaborate on these rules by allowing use of priorities and other elements, these are the basic node logic concepts.

A principal feature of the stochastic model's handling of both nodes and arcs is its capability to accept a variety of PDF's. One program (VERT) [22] can accept 14 PDF's, ranging from the well-known uniform, triangular, and normal, through the more exotic, such as log-normal, Weibull, and Erlang. If none of

these is appropriate, the distribution can be entered as a histogram defined by the analyst. Any or all can be used in a single model. Later network programs also accept large numbers of PDF's.

A significant decision to be made when formulating a network model is the determination of level of detail. Most analysts advise the completion of a "rough-cut" at a fairly aggregated level of detail before attempting to model the fine grained programmatic structure. This allows a more realistic determination of needed level of detail to be made before full commitment, and it also identifies areas which will need to be emphasized in the future. In the earliest stages of program definition (e.g., concept definition), far less than 100 activities can be included. Of course, the inputs are estimates of more highly aggregated sets of activity behaviors, and therefore, they will contain more inherent uncertainty than will be the case as program definition progresses. As plans are defined in more detail, there will be a need to define and include more activities; however, 200-500 have been found adequate by most analysts. Their consensus for analytical (not management control) purposes is that greater detail can tend to obscure major relationships and slow the modeling process unnecessarily.

In the process of structuring the model, analysts do not go directly from activity description sheets to computer terminals. Instead, the actual networks are drawn. Each network computer program users' manual recommends use of a particular set of symbols that define the logic and assist the analyst in ensuring inclusion of necessary inputs. Figure F-2 illustrates some of these symbols.

The work of formulating a network model should not be expected to proceed without some difficulties. Procedure relationships may have to be defined many times as inconsistencies are discovered, weaknesses corrected, and budgets or schedules changed.

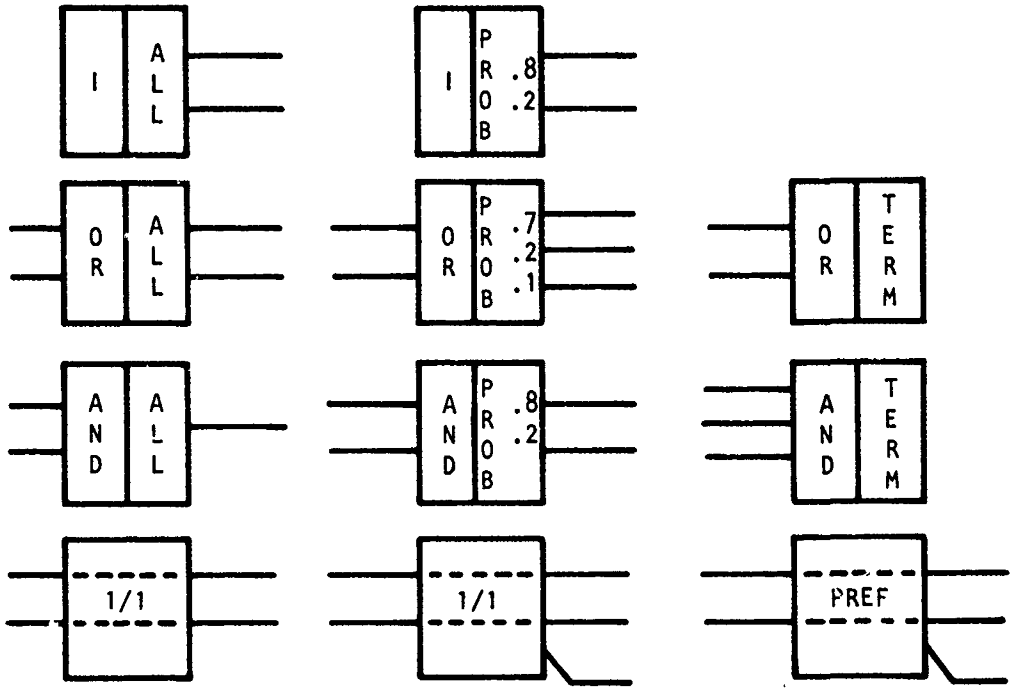


Figure F-2

NODE REPRESENTATION

c. Implementation

When the network is finally judged to be "good enough,"[1] the analysts enter its description into the computer. Specially prepared data formats peculiar to the particular network analysis computer program are used. As can be imagined, the data set may be massive since, for example, in some network models a single activity can require as many as 9 descriptive inputs, and a node as many as 31.

The network analyzers cited herein provide varying amounts of flexibility and realism in their treatment of the variables of

[1]A model is an abstraction whose realism is adequate to its purpose.

time, a statistically independent quantity, or a probabilistic function of time. They may or may not consider technical performance as an uncertain quantity. Another difference is in the treatment of other resources. While VERT, for example, treats only a single resource--cost--others consider a user-defined number (e.g., TRANSIM V)[9], [10].

When the analyst is ready to run his program and has entered his data into the computer, the machine performs a large number of simulations of the execution of the acquisition program. This is assisted by use of a computer subprogram known as a "random number generator", which, in concept, produces a number that lies anywhere between zero and one with uniform probability. Whenever an uncertain event is to occur, the computer program compares that number with a data-generated number representing the probability of the event's occurrence. If the "random number" is within the range of the data-generated probability, the computer program initiates that event. Of course, no single simulation of program execution conveys much useful information; however, when that simulation is complete, the computer has collected data from wherever in the network the analysts programmed for it to do so. It then repeats the process, typically 1,000 to 6,000 or more times. Obviously, one simulation tells very little, and 100 may still not give "typical" statistics. How many repetitions are enough? There is no practical way to be sure, but statistical methods can give indications of what is reasonable. Computer time is now cheap enough so that analysts can increase the number of repetitions until percentages of kinds of data being collected appear to have stabilized. The 1,000 to 6,000 replications will consume not much more than five minutes of computer time, and statistical tests can then be performed to see if the results are reasonably stabilized.

d. Outputs

Even the most rudimentary set of outputs obtainable from network analyzers will contain terminal node information like PDF's,

CDF's, etc. In fact, VERT outputs include frequency distribution (PDF), Cumulative Frequency Distribution (CDF), mean, standard deviation of the sample, coefficient of variation, mode (most likely), and a measure of skewness, plus other statistical measures for all modeled project completions and specified decision points and activities. This output is in a form similar to the output shown in Figure F-3.

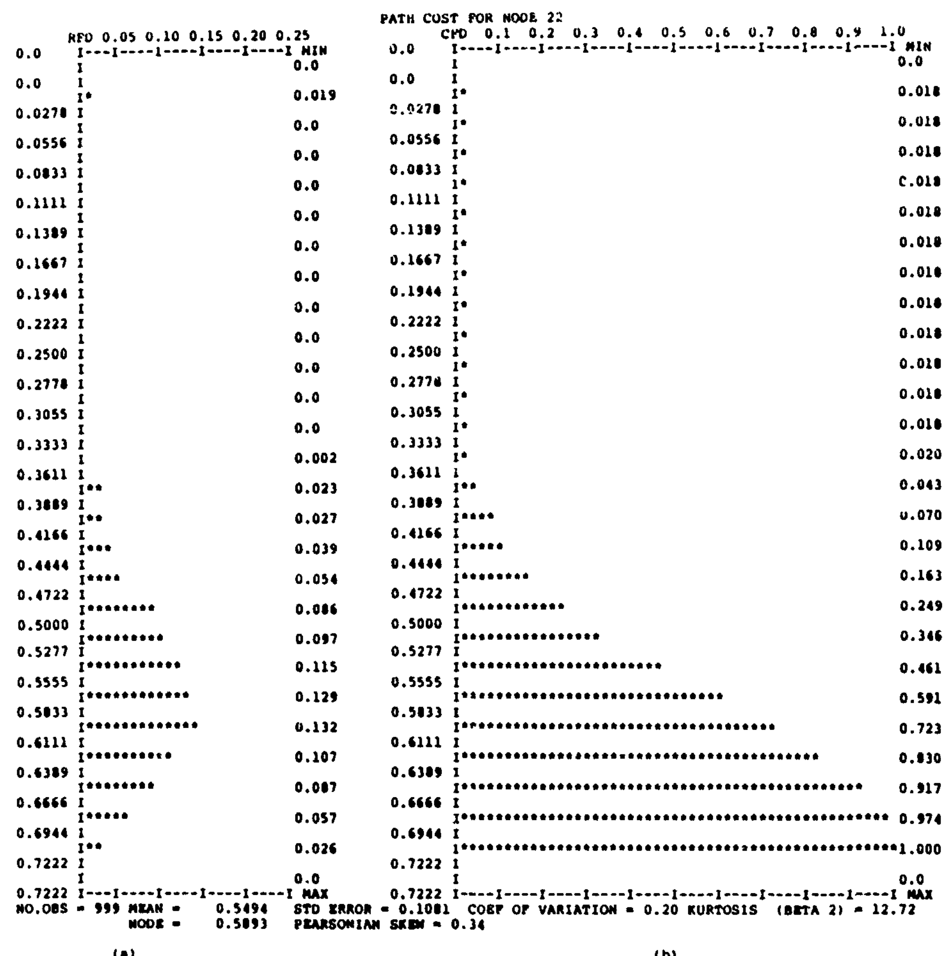
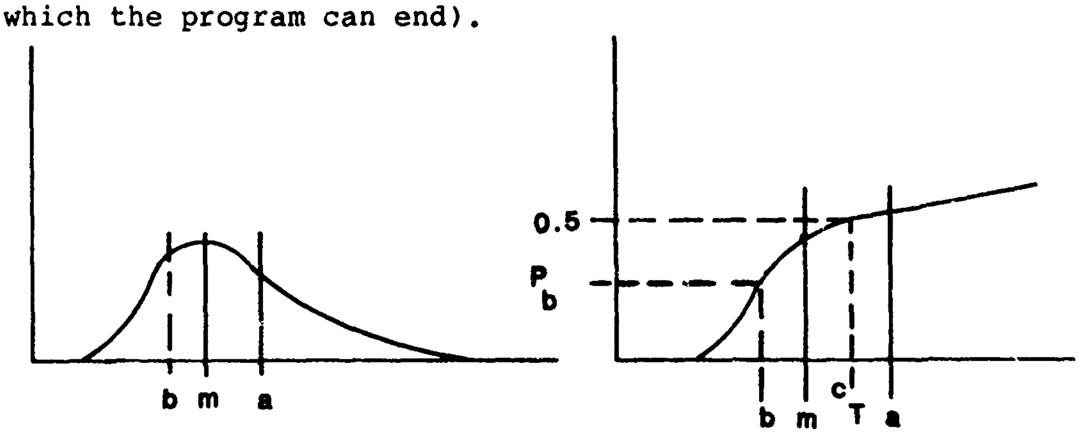


Figure F-3

TYPICAL VERT OUTPUT

There are many software packages available. Their description here is not intended to be an endorsement. Their individual capabilities must be closely examined for any specific application. Examples described here are only to indicate uses discovered during the survey.

Probability function graphics produced include types such as Figures F-4(a) and F-4(b) below for selected internal nodes (that is, decision points in the program) or terminal nodes (ways in which the program can end).



PDF
(a)

CDF
(b)

Figure F-4

DISTRIBUTIONS OF COST AT A TERMINAL NODE

Figure F-3(a) represents an approximate PDF (in the VERT manual called a Relative Frequency Distribution) and Figure F-3(b), a CDF. The former's shape gives intuitive understanding of probabilities and of uncertainty, whereas the latter's allows the making of probability statements such as, "There is a 72 percent probability of costs being at or under $583,300". The statistical information at the bottom tells the number of times the simulation was run to get the curves (NO. OBS), which was 999, the expected, or mean, cost, which was $549,400, and certain statistics describing the curves. The Standard Error gives an absolute measure of variability or uncertainty in the units of the variable being assessed (here it is cost), while the Coefficient of Variation gives a relative measure since it is the ratio of the standard error to the mean. A value near 1 for the coefficient of variation might be considered to show fairly high uncertainty. The other two statistics give more abstract information. "Pearsonian skew" (i.e., skewness) indicates the amount the PDF maximum shifted away from the average, and "kurtosis" tells how

sharply it is peaked. Skewness tells a manager in a qualitative way the strength of belief that the variable will be different from the average. He will obtain meaningful information, also, by looking at the PDF to see what the most likely value is, and then by looking at the CDF to compare the probability of the value being below or equal to the most likely and below or equal to the average.

By looking for the 50 percent point (median) on the CDF (shown only approximately in Figure F-4(b)) he can, for example, see the point which Army TRACE policy says should be used for a budget and compare that with his baseline estimate's probability.

Other outputs of VERT consist of a bar graph of terminal node probabilities. Since a project may succeed or fail in a number of ways, each may be represented by a terminal node. The bar graph gives the outcome probabilities and allows comparisons to be made. The program can even select an optimum terminal node (that which has least cost and completion time and highest performance), or worst terminal node (that in which highest cost and completion time and worst performance results.)

In many analyzers, this information is supplemented by indices of criticality for specified arcs and nodes. ("Index of criticality" means the probability of an arc or a node being on the critical path.)[2] Other statistics available with various analyzers (e.g., RISNET [23]) include probability of reaching specific terminal nodes (i.e., of a program's ending in a specific way) and joint time and cost distribution (i.e., the probability that final specified limits on both time and cost will be exceeded).

---

[2]It should be remembered that in probabilistic networks, different variables and paths chosen by the uncertain nature of the program will cause simulations to have critical paths which are not necessarily the same each time. See Appendix B, Definition of Terms for the definition of "Critical Path".

Managers can use these outputs for decision making in the following ways. Suppose Figures F-4(a) and F-4(b) represent the probability density function and cumulative distribution function of cost at a terminal node, which itself represents completion of an important milestone.

Typically, a value such as b in the two figures represents the Baseline Cost Estimate submitted by the PMO; but Figure F-4(a) clearly shows that the most likely cost is somewhat higher, at m, and that the expected value is even greater, at a.[3] Figure F-4(b) shows even more clearly what the situation is. The probability of not exceeding b is only p_b, while the cost level that has an even chance of being exceeded or not is c_T (statistically, the median--also the level of the TRACE). Figure F-4(b) can also be used to set a cost level consistent with the manager's assessment of a reasonable level of risk. For example, if he considers that a risk of failure to cover costs should not be greater than one in five (the 20 percent level), he can set his budget requirement at the 80th percentile cost.

A flexible computer program supporting probabilistic network assessment is TRANSIM V [9] and [10]. This computer model lends itself to use in detailed budgeting and day-to-day project control. The utility of this model is not obtained without effort but is valuable for the insight a manager can have into program status and direction. The data input requirements, however, expand in proportion to the level of detail in the output. For example, for each activity explicitly described in the network a responsibility is named. This allows summaries by name to be included in the output but obviously requires more data preparation.

TRANSIM V provides the following 20 reports: (Note - TRANSIM is but one example of the many programs available that analyze networks).

---

[3]"Expected value" is defined in probability as the average for many runs, not what can be expected to occur. The latter would be a prediction, not a probability statement.

- o List of Names Used in the Model
- o Summary of Number of Words of Data Storage Used
- o Schedule Risk Report
- o Time Summary Graph
- o Criticality Analysis Report
- o Activity Criticality Report
  - With Predecessors, sorted by Activity/Milestone Code and/or Decreasing Criticality
  - With Successors, sorted by Activity/Milestone Code and/or Decreasing Criticality
- o Activities Delayed Awaiting Resources
- o Activity/Milestone Probability of Occurrence Report
- o Activity/Milestone Schedule, sorted by
  - Activity/Milestone Code
    and/or
  - Earliest Start Times
    and/or
  - Expected Start Times
    and/or
  - Latest Start Times
    and/or
  - Earliest Finish Times
    and/or
  - Expected Finish Times
    and/or
  - Latest Finish Times
- o Activity Schedule Graph
- o Activity Code and Description for Schedule Graph
- o Resource Utilization History
- o Resource Requirements Graph
  - Schedule
  - Summary
- o Activity Code and Description for Resource Requirements Graph

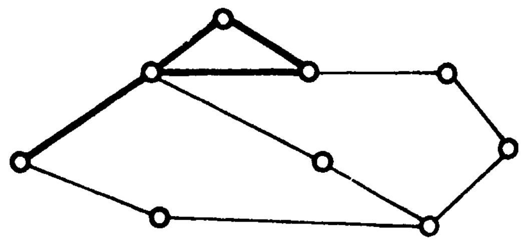
- o Aggregate Resource History
- o Aggregate Resource History Graph
  - Schedule
  - Summary
- o Activity Code and Description for Aggregate Resource History Graph
- o Cumulative Aggregate Resource History Graph
- o Aggregate Resources Summary Graph
- o Activity Status Reports
  - Activities Underway for Responsibility
  - Activities Due to Start
  - Activities Due to Complete

These reports can be printed out selectively. To describe each report in detail would add unnecessary bulk to this handbook. It is sufficient to summarize as follows:

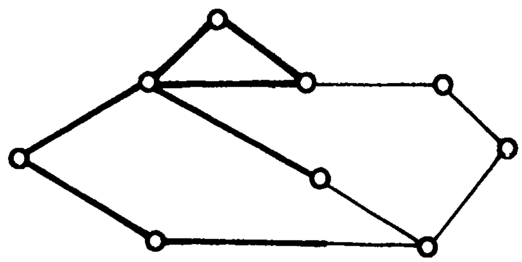
The reports provide probability of completion by scheduled date and combine the information with actual calendar dates when desired. PDF's and CDF's can be obtained for any activity or decision point. Designated risk levels can be used to determine when each activity is expected to reach that level, and this information can be supplemented by a reading of the number of days between reaching that level and the date of scheduled completion. As in other network models, criticalities (probabilities of being on the critical path) are given, but TRANSIM V reports also provide summaries by responsibility. An evaluation is also given of program-wide criticality, which the program manager can use as a general status evaluation. Since each inputs resource is limited (there is a fixed resource pool size) during any activity, and since the resource cost per unit for each activity can also be defined, the manager can obtain detailed and aggregated resource and cost history information plus probability evaluation of future resource and funding requirements. The reports needed to update the model inputs are made periodically, as decided by the

program manager, by whatever level of management he decides provides him with necessary detail; therefore, he can establish a system of information and projection which allows him to carry out control functions.

Other variations of outputs concern budget information provided by various network analyzer computer programs. For example, VERT produces two types of cost data for each selected decision point and for each terminal point. The first type, called "path cost", provides the cost distribution of all activities on the path (sequence of activities) which led to that node (during each run). The second type, called "overall cost", provides not only the path cost but adds to it the cost of all activities processed prior to the completion of the decision point and provides the distribution of this value. Such information can be collected to provide overall budget estimates [22]. These costs are illustrated in Figure F-5 by the darkened lines.



PATH COST



OVERALL COST

Figure F-5
ACCUMULATION OF COST DATA

In computer programs that track multiple resources (such as TRANSIM V), the budgetary information can, in principle, be at the level of detail of appropriation category or even budget account (however, no examples of these levels of detail have been found in actual use).

3. DECISION ANALYTIC METHODS

a. Introduction

Decision analysis provides a framework for greater depth in risk assessment than do other approaches. A cricital person might feel that many of the existing risk assessments will not necessarily assist a manager in making a decision. The manager may know more facts but feel that he has no more insight into the effects or desirability of alternative decisions. The more extensive applications using decision analysis should overcome this problem, since the core of decision analysis is the determination of a decision maker's pattern of preferences so that he can be logical and consistent in satisfying those preferences.

While the advantages of decision analysis are real, a manager cannot just tell the people who are applying a network model approach to change approaches. Of the literature researched for this handbook, the only examples of the decision analytic approach found were those of a small group of U.S. Army analysts [12], although it is understood that Naval War College Faculty personnel have used this method also. (The principal service methodological works are [12], and [13], and [14].)

In the application of this method, the analyst's approach is more like a comprehensive systems analysis than the methods discussed previously in this appendix. For example, the author of [13] says:

"As a basic objective of risk analysis is to create a quantitative and experimental laboratory to study program success, the general methodology for a risk analysis is quite simi-

lar to the steps involved in systems analysis, systems engineering, or industrial dynamics. The steps include the following:

1. identify objective
2. state alternatives
3. collect data
4. construct model
5. simulate/apply model
6. validate model
7. obtain criteria and trends"

The same author discusses risk analysis objectives in general:

"It is important to ask ourselves whether or not risk analysis contributes to acquisition management. A risk analysis should identify the following areas to the acquisition personnel:

1. potential problems areas
2. consequences of failure
3. low risk program areas
4. requirements versus state-of-the-art trade-offs
5. adequacy of acquisition time
6. sufficiency of appropriations
7. optimum allocation of funds
8. data gaps/recommend studies and concepts
9. sensitive/critical parameters"

It is clear that the author of the quoted paragraphs conceives of a study requiring depth of investigations, breadth of knowledge, and significant effort--a study which contributes insight into many aspects of the program under assessment.

b. The Model

In the decision-analytic approach, the program model is formulated by reference to a decision tree in which the elements are the major decision points in program development. Although the tree itself may never be drawn, all relevant events must be listed and an analysis made to determine problems that can occur during each phase of the process of arrival at the decision points. Experts are consulted to identify each problem and possible problem resolution which will be considered (keeping in mind the desirability of restricting the proliferation of the

tree), and to assign probabilities to the various problems and resolutions. Any realistic and convenient number of sequential resolution efforts can be postulated.

Each problem is defined so that it is independent of the others; that is, knowledge of its occurrence/nonoccurrence does not alter the probability of occurrence of any other.

A first item of input required for each possible problem resolution is its cost. The reader will recognize that the elements of this model are such that the output will be probabilities of success or failure and expected costs. The inputs can be tabulated as in Table F-1, where P_O^1 is the probability of occurrence of problem 1, P_O^2 that of problem 2. R_1^2 is the first resolution of problem 2, R_2^2 the second resolution of problem 2, and P_S^{21} is the probability of success for the first resolution of problem 2, P_S^{22} the probability of success for the second resolution of problem 2.

Table F-1

DECISION ANALYSES PROBLEM/RESOLUTION TABLE

Potential Problems	Probability of Occurrence	Possible Resolutions	Probability of Success	Cost Impact
1	P_o^1	R_1^1	P_s^1	C_1
2	P_o^2	R_1^2	P_s^{21}	C_{21}
		R_2^2	P_s^{22}	C_{22}
3	P_o^3	R_1^3	P_s^{31}	C_{31}
		R_2^3	P_s^{32}	C_{32}

The entries of cost impacts are the costs required to obtain the corresponding resolution. For example, C_{32} is the cost of applying resolution 2 to problem 3.

Having determined the information needed for this kind of table, the analyst defines the events which are the combinations

of problem occurrence and non-occurrence and their resolution and non-resolution.

c. Implementation

To implement the model, the analyst enters his decision tree information as a network into any available probabilistic network computer program. The probabilities he has formulated will determine the cost and performance outcomes of each completion of the decision sequences. After a large number of repetitions, he can take the outputs collected to obtain values permitting the plotting of such graphs as Figure F-6.

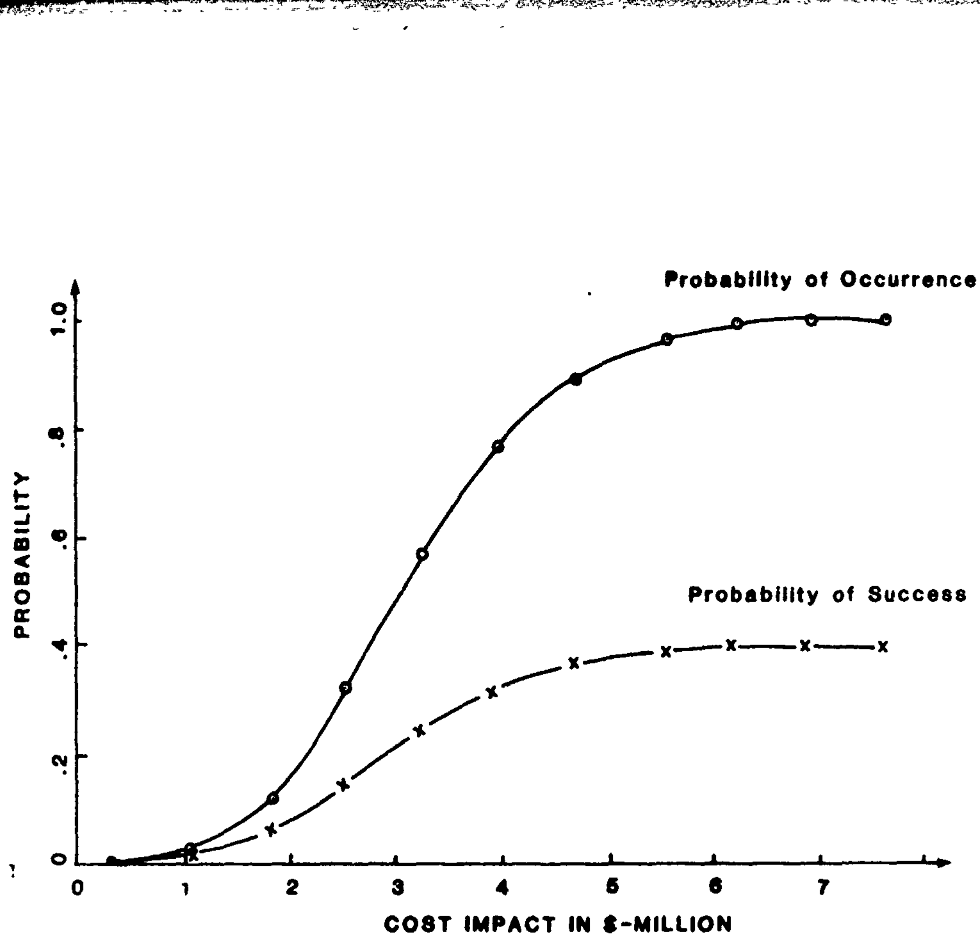
d. Outputs

Outputs are exemplified by Figure F-6. The analyst can see from the curve labeled "probability of occurrence", for example, the cost growth corresponding to the 50 percent probability of occurrence (which would provide a TRACE under this analytical approach--in the figure, about $3 million).

So far we have information similar to that produced by other risk assessment techniques plus that from having the "probability of success" curve on the same axis. Perhaps not all of the risk area "identifications" (as recommended in the passage quoted previously from [14]) have been made, but the approach does interrelate performance, cost and risk in a form amenable to tradeoff.[4] Note that this analysis shows that for any level of cost growth (impact), probability of program success does not exceed about 0.4.

The presentation of information typified by Figure F-6 is insufficient for budgetary purposes as shown; that is, there is no appropriation category or budget year breakdown. There is no

[4][6] also describes one of the more elaborate network models, RISNET.



COST (K$)	PROBABILITY OCCURRENCE	CUMULATIVE PROBABILITY	PROBABILITY SUCCESS	CUMULATIVE PROBABILITY
0	0.000	0.000	0.000	0.000
724	0.004	0.004	0.001	0.001
1,445	0.022	0.026	0.014	0.015
2,172	0.094	0.120	0.045	0.060
2,896	0.202	0.322	0.086	0.146
3,620	0.243	0.565	0.097	0.243
4,344	0.200	0.765	0.076	0.319
5,068	0.128	0.893	0.046	0.365
5,792	0.066	0.959	0.019	0.384
6,516	0.027	0.986	0.007	0.391
7,239	0.010	0.996	0.002	0.393
7,963	0.003	0.999	0.000	0.393
8,687	0.000	0.999	0.000	0.393

Figure F-6
COST IMPACT DISTRIBUTION

reason in principle, however, why the specified model phases cannot be the fiscal years, or that analysis at the appropriation category level cannot be carried out. Since no analyst has accomplished this yet, extra effort would be needed to ensure adequacy of application.

The outputs available from another decision analytical approach to risk assessment (Probabilistic Event Analysis - PEA) include those shown in Figures F-7 and F-8 taken from [24]. These figures, which are really combinations of worksheets and results, provide a summary level form of budget risk analysis.[5]

4. THE METHOD-OF-MOMENTS

a. Introduction

The method of moments provides a way to determine the distribution of an uncertain cost that is some function of other uncertain costs. The function may involve summation, multiplication, exponentiation, or a combination.

Probability theory includes various theorems for determining the probability distribution of uncertain values which are sums or products of other uncertain values. However in many cases, the assumptions that must be made to keep the mathematics tractable so restrict matters that applications to real systems are either useless or impossible. Previous to the method-of-moments, the complexity of project element interrelationships has made project models too difficult or impossible to solve mathematically. This is one reason why the technique of simulation has gained favor. However, now that the long-neglected method-of-moments has been reexamined, investigators have devised mathematical methods for solving a number of project management problems with simple computer or hand calculator routines. The theory behind these techniques is found in [20], and some of the actual applications are presented in [26] and [27]. Discussions of aspects of them appear below.

---

[5]The unique aspect of the decision analytic approach--the use of utility theory--is described in [9]; however, no application of that theory has been found in any of the papers reviewed for this handbook.

Program Elements and Milestones 1	Prob. of Occurrence P(A) 2	Cost Impact to Element C_A 3	Prob. of Occurrence P(B/A) 4	Prob. of Occurrence P(B) 5	Cost/Schedule Impact to Other Program Elements C_B 6	Date of Impact Calendar Date 7	Date of Impact FY 8	Expected Loss E(1) 9	Adjusted Expected Loss AEL 10
Vehicle									
1. Armor	.20	$3.0M		-	-	4/78	78	$ .6M	$ .8M
2. Suspension	.80	$ .4M	1.0	.80	$1M, 2 MOs*	6/78	78	$ .84M	$1.12M
3. Tracks	.25	$ .8M	-	-	-	6/78	78	$ .2M	$ .27M
4. Power Train	.60	$1.5M	.75	.45	$4M, 2 MOs*	9/78	78	$2.7M	$3.6M
5. Engine	.20	$ .5M	1.0	.20	$ .5M, .1MO* Engine Qualification	9/78	78	$ .2M	$ .27M
6. Integration	.75	$ .2M	1.0	.75	$2M, 2 MOs*	11/78	79	$1.65M	$2.2M
7. Initial Acceptance Testing	.70	0.0	1.0	.70	$6M, 3 MOs*	2/79	79	$4.2M	$5.6M
8. OSD Review	.60	0.0	1.0	.60	$2.5M, 1 MO*	7/79	79	$1.5M	$2M
9. DSARC	.30	0.0	1.0	.30	$4M, 2 MOs*	10/79	80	$1.2M	$1.6M
							Totals	$13.09M	$17.46M

*Total Program Schedule Slips

PROJECT Y
WEAPON SYSTEM RISK ASSESSMENT

Figure F-7

Program Elements 1	Date of Impact Calendar Date 2	Expected Slippage Prior to Given Element (Months) 3	Probabilistic Date of Impact Calendar Date 4	FY 5	ABL 6		RISK CAPITAL
Vehicle							
1. Armor	4/78	0.0	4/78	78	$ .8M	FY 78	$2.19M
2. Suspension	6/78	0.0	6/78	78	$1.12M		
3. Tracks	6/78	1.2	7/78	78	$ .27M		
4. Power Train	9/78	1.2	10/78	79	$3.6M	FY 79	$11.67M
5. Engine	9/78	2.1	11/78	79	$ .27M		
6. Integration	11/78	2.1	1/79	79	$2.2M		
Program Milestones							
7. Initiate Acceptance Testing	2/79	3.6	5/79	79	$5.6M		
8. OSD Review	7/79	5.7	12/79	80	$2M	FY 80	$3.6M
9. DSARC	10/79	6.3	4/80	80	$1.6M		
					Total		$17.46M

RISK COST ALLOCATION

Figure F-8

b. The Model

To use the method of moments, the first item needed is a mathematical model. If cost is the variable, a convenient model is a Work Breakdown Structure [21]. The model structure represents the analyst's concept of the objective aspects of the total model.

Since the major advantage of the method of moments over the method of probabilistic network analysis is that it simplifies the effort, it is appropriate to keep the problem concept simple also. The model defined should not be encyclopedic, and indeed, some investigators have recommended that no more than 20 or 30 elements be included in the model, although as many as 63 are mentioned in [26]. On the other hand, the more the model elements are aggregated, the less likely it is that an expert can give credible estimates of uncertain values. The analyst must choose a compromise, and no scientific principle tells him how to do so.

c. Implementation

The first and easiest application is that developed in [26]. The application allows the analyst to obtain two output probability curves. These represent two extremes, that of complete statistical independence and that of complete dependence. The two bracket an unknown exact probability curve that represents the integration of all the uncertainty information in an additive cost model. This is necessary because only the extremes of complete independence of all component values, on the one hand, and worst-case dependence of the dependent component values, on the one other hand, are easily solved.[6]

---

[6] For those with some background in probability, we assume that the values that are correlated have a complete positive correlation; i.e., a correlation coefficient equal to one. This provides a "worst-case", while independence provides a "best-case".

The method makes use of another simplifying assumption: that for the case with dependence, a normal resultant CDF can be used based on a PDF with the mean and variance determined by the mathematics of this application. Although it is clear that the true resultant cannot be exactly of the normal form (costs cannot go negative), the approximation is nonetheless useful when there is a reasonably large number of input uncertain values (greater than 25 seems reasonable, as long as no one value strongly dominates the results).

As an example, let us take a cost model devised so that all elements add to a total, and none has multiplication or division of one uncertain value by another or uses any in an exponential expression.

Having first defined the model, the analyst's next task will be determination of quantitative estimates of the cost element variables and of the uncertainty surrounding them. (Do not forget that uncertainty is a subjective property of the expert, not an objective property of the costs.) There are a number of methods for obtaining the quantitative statements of uncertainty discussed in Appendix D, but none are perfect. This part of problem model formulation represents a sensitive area, and the program manager who is interested in the quality of a risk assessment will be concerned to ensure that efforts have been made to obtain consistent probability assessments reflecting the experts' opinions as accurately as possible.

In keeping with the spirit of simplification, it is possible to consider the PDFs describing the experts uncertainty to be representable by only two types: triangular, as in Figure F-9, and uniform, as in Figure F-10. We need both the triangluar PDF and the uniform PDF to satisfy both the expert who is willing to give a range of possible values (e.g., costs) and a most likely cost, and the one who is unwilling to say that any cost is more likely than any other value within some range.

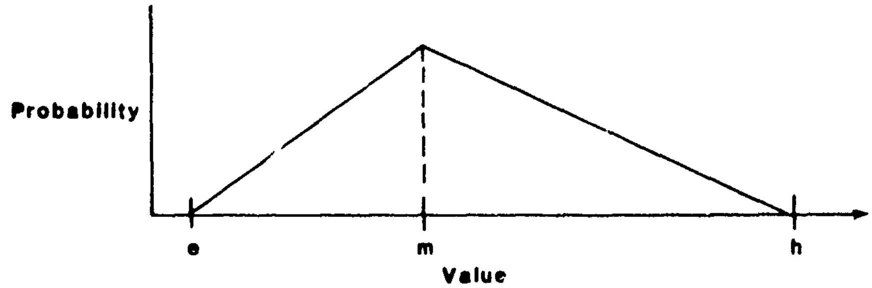


Figure F-9
TRIANGULAR PDF

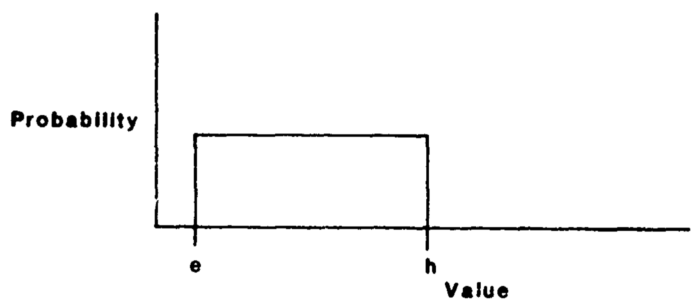


Figure F-10
UNIFORM PDF

The data for all of the uncertain costs can be collected on a form similar to that of Figure F-11 (modified from [27].

Project ____________ Analyst _________________ Date ______

INPUTS						RESULTS		
ELEMENTS	Low	P	Most Likely	High	P	Mean	Var	St.Dev
1.								
2.								
3.								
TOTALS								

BUDGET _________. NOMINAL _____. BUDGET CONF ____.__th PCTL____

Figure F-11

DATA COLLECTION/WORK SHEET

In using the form of Figure F-11, the analyst fills in the <u>Input</u> section with the names of the cost elements and the values given by his panel of experts at the probability levels (P) with which they are confortable. By means of hand calculator programs[7] he computes the results to the right of each element and adds them in accordance with the following rules:

(1) Add all mean values.

(2) Note all elements having a dependency on each other. Add their standard deviations and square them to obtain a "variance" of their sum. Add that to the sum of the variances of all other elements.

(3) Find the square root of the value resulting from step 2.

(4) Determine the cumulative normal distribution for the uncertain value having the total mean found in step (1) and the variance found in step (3).

---

[7] The needed programs do not appear in any of the references, but writing them from information in the references should be relatively simple.

Having completed one set of outputs, the analyst should now repeat the computations, but this time add <u>all</u> variances (no standard deviations). This gives the output for a model, the inputs of which are all independent. The two curves then form bounds on the "true" output distribution.[8]

This "true" distribution provides the information needed either to understand what the experts have been saying collectively about the proabibility of not exceeding a budget, or to calculate a budget which has a manager-selected probability of not being exceeded.

d. <u>Outputs</u>

Figure F-12 exhibits the kind of simple display obtainable by use of hand calculator programs. The display is printed on a tape, which accounts for the normal CDF being presented vertically. The graph shows the analyst that he needs $59.44 in order to have three chances out of four of not exceeding his budget.

It also shows that the mean value (the same as the most likely <u>and</u> the 50th percentile when a normal CDF is used) is $52.89; that the standard deviation is $9.72, or 18 percent of the mean; and that his budget, $45.00, has only a 21 percent chance of not being exceeded. The maximum and minimum amounts given by his panel of experts totalled $76.00 and $31.00, respectively.

Of course an additive model is a simplification. Furthermore, results of network simulations show that interdependencies limit the use of a normal distribution in programs of any great complexity. Consequently this sort of a model should be regarded only as a first approximation, to be refined as resources permit.

---

[8]The unknown distribution is "true" in the sense that it lies between known bounds. It cannot actually be true since it is a normal distribution, which we chose in order to simplify the problem.

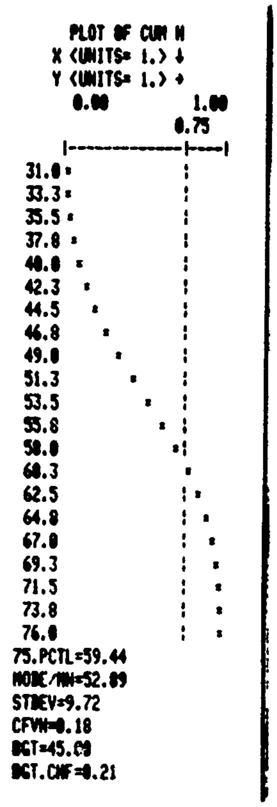


Figure F-12
METHOD OF MOMENTS HAND CALCULATOR OUTPUT

The authors of [26] also refine this approach in [27] showing the applications for multiplicative and other, more complex functions of uncertain quantities. They then use the moments derived to formulate another type of PDF and CDF in place of the normal distribution shown herein. This other type of PDF possesses the advantageous features of being flexible in shape, the shape being dependent on the values of parameters used in their formulas. The moments found using the method-of-moments allow an analyst to define the parameters for this type distribution so that it will fit the mathematical relationships of the uncertain inputs to the analyst's model.

Another approach to the problem of dependency is that developed in [31]. In this paper, dependencies are assumed to stem from an underlying but unknown factor, so that the observed (or estimated) uncertain values are assumed to be actually different

functions of one independent uncertain value and another, underlying one common to all the seemingly dependent higher level values.

The ambitious analyst may wish to pursue this approach, but must be careful to assure himself that he restricts the dependent uncertain values to those that truly appear to be dependent.

The foregoing paragraphs demonstrate an approach that can assist a manager of a small program. To avoid mathematically complex explanations in this handbook, a simplistic approach was used, and therefore the power available in the method of moments has not been shown. The more mathematically adept analyst wishing to exploit the method more fully is advised to read [20], [26], [27], [30], and [31].

5. WBS SIMULATION METHODS

a. Introduction

This method stems from the same viewpoint as the method-of-moments, that a cost estimate is composed of element costs which cannot be known with certainty. A cost estimate is usually shown as a sum of element costs, but the element costs themselves may be composed of subelement costs which are multiplied together or are exponents, or have some other relatively complex mathematical assocation. As was stated in paragraph 4.a., this has made the determination of the PDF of total cost from the PDF's of the element and subelement costs so difficult as to be a practical impossiblity until recently. This situation has changed bacause of the method-of-moments and the availability of powerful, relatively inexpensive computers. The WBS simulation technique makes use of the power of a computer to repeat a complicated set of computations a great many times, so that a large number of cost estimate possibilities can be collected to see how frequently they each occur. From the frequencies the computer can form a PDF.

b. The Model

The model for this technique is the basic cost breakdown of the program cost estimate. Usually this consists of a WBS combining engineering and functional elements for which costs can be estimated. The element costs must (as in the method-of-moments) be further described by probability statements like PDF's. With some of the methods ([5], [6]) it is necessary to define the elements in such a way as to ensure their statistical independence (see Appendix E) while in others [15] dependence is conceptually included. In some of the methods, the model includes a few conceptual sources of possible error in the estimates, and a computer routine picks the source considered to override the others, and thus selects the PDF associated with that source.

c. Implementation

Consideration of model size applies here as in other techniques; it is helpful to keep the number of cost elements down to a convenient size--perhaps sixty or less. This will permit both detailed data gathering and also visibility of major effects.

In some of the WBS simulation methods, the analyst or subject matter experts who provide cost estimates and ranges also choose PDF's by shape from a selection provided by the analyst. After the analyst has checked to ensure consistency, he enters all the costs and PDF's into the computer. The computer produces results based upon assumptions of dependence and independence, and certain extremes of input PDF shape (which is related to uncertainty). This range of outputs allows the analyst to see the limits resulting from assumptions regarding dependence and relative uncertainty.

In [5], selection of the cost element PDF is made by the computer after the analyst has described four sources of cost estimating error (uncertainty). These sources must be described as

independent of one another. The four sources are: estimating technique or its method of application; program schedule; technology advancement; and system configuration. The analyst inputs four quantities, the most-likely cost of the element (normally the single point cost estimate) and three other numbers for each error source as it affects the element. These three numbers are the highest and lowest cost that the error source could cause, and a measure of uncertainty. The uncertainty numbers are derived from the verbal descriptions, "low", "medium low", "medium high", and "high", by reference to typical PDF's that can be described as showing those uncertainty ranges.

d. Outputs

The various computer programs developing this basic technique output somewhat different information, but the three reviewed for this handbook do have certain similarities. All three include tables of probabilities for each cost increment selected and probabilities that total cost will not exceed given dollar amounts. This is essentially the information contained in a PDF and a CDF, and two of the programs [5] [6] plot the resulting CDF's and print various statistics like mode (most likely) and mean (average) and costs corresponding to selected probabilities. One of these computer programs [5] also plots the input PDFs for examination and another [15] prints the CDF information resulting from assuming independence or dependence plus that resulting from extreme assumptions of uncertainty.

G. THE GRAPHIC METHOD

a. Introduction

The preceding sections of this Appendix have included one exposition of a summary level application (the method-of-moments). This method was described so that managers of programs enjoying lower levels of support might be able to accomplish some level of cost risk assessment. This section provides another summary

level method for those program managers who cannot obtain support for more searching assessments. The graphic method is the product of the author of [17], and his paper recounts the need for summary method approaches. As he says,

"The effort expended and care taken in obtaining risk data, plus the cost of developing and running a computer model, tends to limit the use of risk assessment to major programs or to larger companies where sufficient resources are available. Therefore, in order to broaden the application of risk assessment, an alternate and simpler technique was developed. The technique provides a viable risk assessment that is independent of the computer, although it requires some constraints on the flexibility, accuracy and usefulness of the resultant analysis. The computer simulation model is replaced by a 'manual model'. A pencil is used instead of the keypunch and computations on a hand held calculator replace the computer itself. The manual method, while not as comprehensive as the computerized one, provides a rapid and less costly means of preparing small analyses....this technique can serve as an important first step which may pave the way for future use of a more sophisticated computer model methodology."

A weakness of the method described is that it produces a set of probability density functions, as descriptions of expert uncertainty, which are intuitively unsatisfying (see Figure F-13).

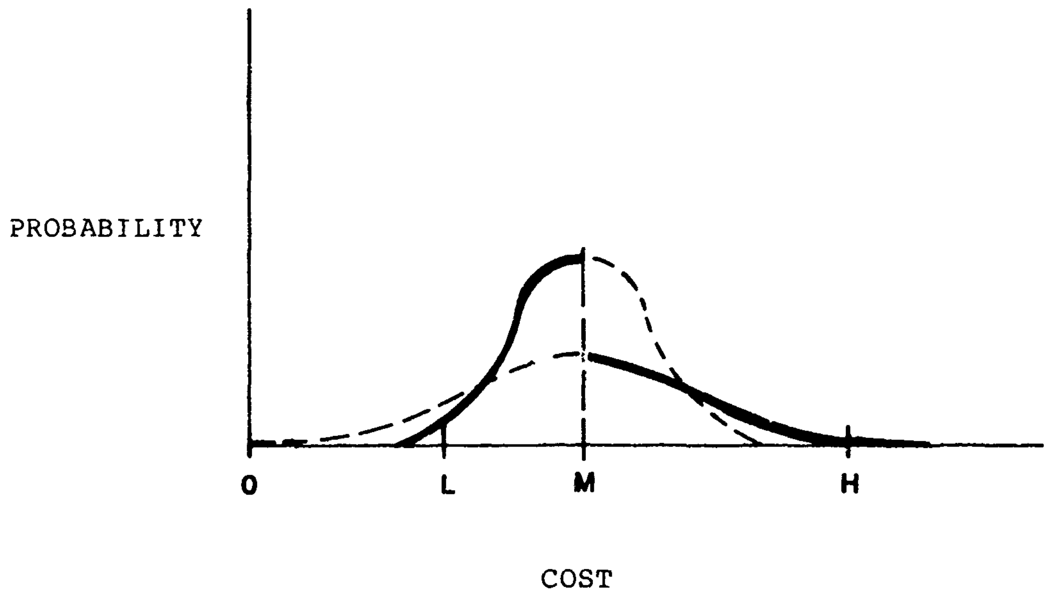


Figure F-13

EQUIVALENT DENSITY FUNCTION FOR GRAPHIC METHOD

The strength is that the PDF's do contain a certain intuitively desirable feature, skewness, and they are easy to work with.

b. The Model

Like other methods, application of this method starts with the establishment of an additive cost model. As with the simplified method of moments, the analyst must define cost elements that are statistically independent, and he will want to restrict the number of elements to a size that he can handle adequately; i.e., 20 to 30.

With his model and the list of cost elements as a basis, the analyst next obtains expert estimates of costs and cost ranges. In this approach it is necessary to obtain a 50th percentile cost as the central estimate; the experts are asked to estimate the cost for which the element has as great a likelihood of overrun as underrun. The expert then estimates two extreme cost values and their associated probabilities. These three values should represent the 50th percentile and 2 extreme points having equal probability differences with 50 percent (e.g., the 5th and 95th percentile). This method assumes that the higher should be farther from the central value than the lower. In other words, the distribution function should have a righthand skew. Many risk and cost analysts find righthand skewness desirable because it estimates that costs are more likely to overrun than underrun. Whereas in some other methods the right skewed distribution is modeled as a triangle or a well-known skewed curve, in this method curves are used that are halves of normal distributions.

The unusual feature of the graphic method is its ease of deriving a skewed curve to represent an individual's uncertainty in estimating a cost. The method is easy because the analyst can make use of graph paper designed so that a straight line on it represents a cumulative normal distribution function, and a user has only to plot two points or a point and a line to obtain such

a distribution. Figure F-14 shows a plot of two lines for the three points estimated by the expert. Figure F-13 shows what the two-line plot has represented in terms of normal density functions.

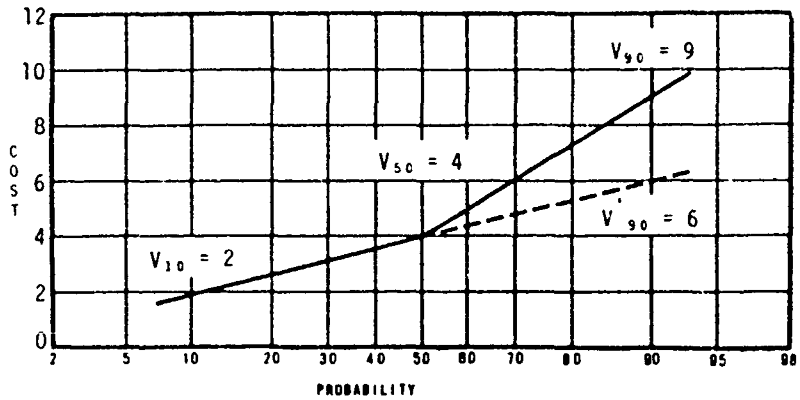


Figure F-14

ELEMENT PROBABILITY CURVE

The solid (discontinuous) curves serve as the three-point density function, where the left side is the left side of a low variance normal density function and the right side is that of one having a relatively high variance. Since normal density functions are symmetric, there is an area of 0.50 under each half curve; thus the three-point function integrates to the value 1.

This synthetic curve looks like no standard, defined probability density curve. It is discontinuous, and it extends to negative numbers, however it <u>is</u> easy to manipulate. It also has the desirable feature of being skewed to the right. It should be noted that although the density function is discontinuous, the cumulative distribution function (see Figure F-15) is not. In other words, the expert can still say meaningful things about the chances of costs being less-than-or-equal-to any number covered by the curve.

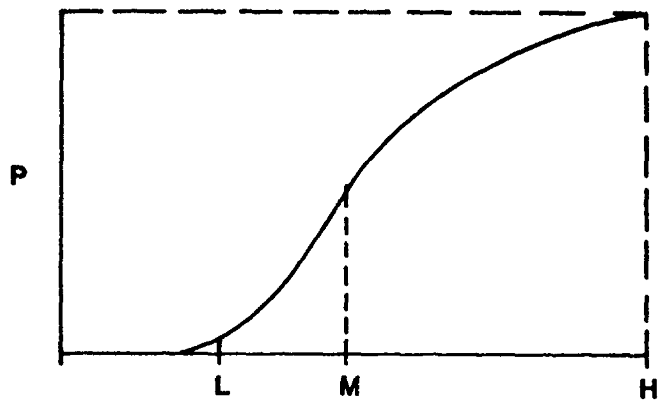


Figure F-15

CDF FOR GRAPHIC METHOD

c. Implementation

This summary method gives a way to combine the uncertain cost element distributions for cost elements which are to be added. The method has not been justified by theory, but the originator inferred it from the results of simulations, and the inferrence from those results of a few easily applied algebraic rules. The rules, taken from [17], are presented below. Start with the following definitions:

- V_{10}, V_{50}, V_{90} - the values plotted as the 10th, 50th, and 90th percentile for a given cost element. (V_{10}, V_{90}, and V'_{90} may not be the expert-supplied values but derived from the normal paper plot).

- Skew - the percent deviation from a straight-line extension of the left hand half-line at the 90th percentile. That is, it is the difference between V_{90} and a value V'_{90} found by extending the left half-line (as in Figure F-14). Note that:

$$V'_{90} = 2\,V_{50} - V_{10}.$$

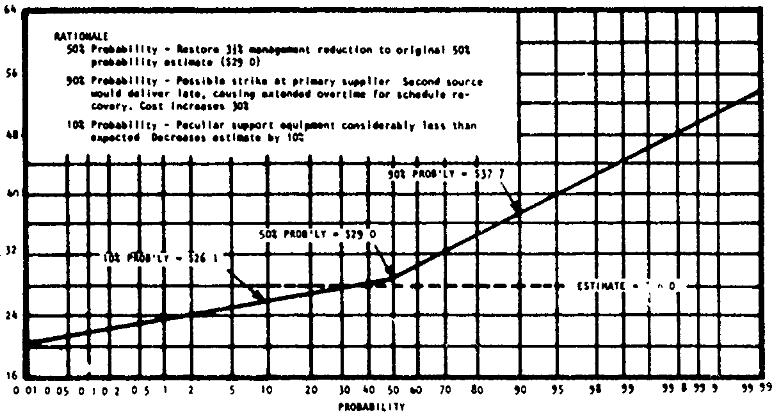


Figure F-16

DETAIL OF ELEMENT CURVE

To determine values for finding a cost distribution which is that of a sum of the element costs, for each cost element:

(1) Add all V_{10}, V_{50}, and V_{90} values, respectively.

(2) Find skew for the new points = $(V_{90}/V'_{90}) - 1$.

(3) Find a factor, F_A, as follows:

$$F_A = 0.4 \times (\text{skew})$$

(4) Find a value for a factor, N, related to the number of cost elements, from the following:

Number of Elements	N Value
2 to 4	0.6
5 to 10	0.7
11 to 19	0.8
20 to 30	0.9

(5) Find another factor, F_B

$$F_B = N \times F_A$$

(6) Adjust the V_{10}, V_{50}, and V_{90} sums to obtain resultant values, denoted RV_{10}, RV_{50}, and RV_{90} as follows:

$$RV_{10} = (1 - F_B)\ V_{10}$$
$$RV_{50} = (1 + F_B)\ V_{50}$$
$$RV_{90} = (1 + 0.5\ F_B)\ V_{90}$$

(7) Calculate the mean of the resultant distribution in three steps:

- o First find the skew of the resultant, Rskew.

  $$Rskew = (RV_{90}/RV'_{90}) - 1.0$$

- o Then find the F_A factor for the resultant, RF_A.

  $$RF_A = 0.4 \times (R\ skew)$$

- o Last, find the expected value (mean), REV.

  $$REV = (1 + RF_A)\ RV_{50}$$

(8) Complete the evaluation by plotting the new values and the cost levels of interest, as in Figure F-17.

d. Outputs

Figure F-17 shows two "curves" and an estimate. The dashed curve represents the result of summing the original V_{10}, V_{50}, and V_{90} values. The solid curve represents the adjusted values found with RV_{10}, RV_{50}, and RV_{90}.

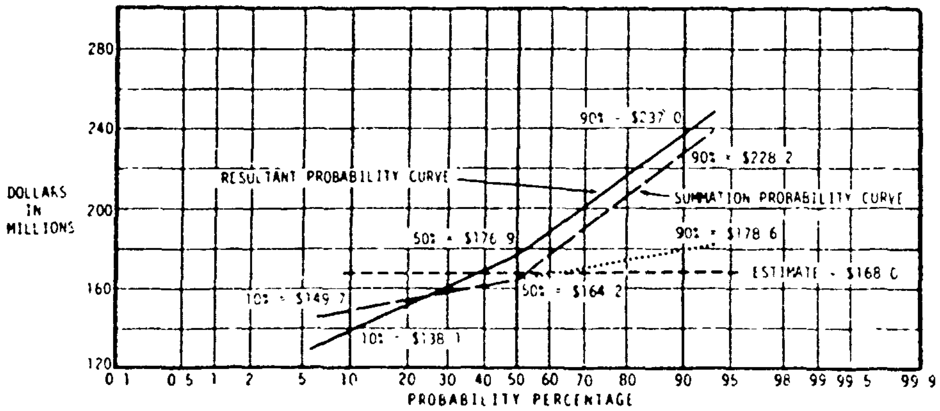


Figure F-17

RESULTANT AND SUMMATION PROBABILITY CURVES

The horizontal dashed line in Figure F-17 is the cost level of interest, which could, for example, be a budget. The method's originator comments as follows:

"Note that the original summation curve has a 50 percent probability of being $4 million less than the estimate. However,

after transformation to the resultant probability curve, the value at 50 percent probability is $9 million above the estimates. The probability of achieving the estimate has dropped to 40 percent and the value at 90 percent probability is $237 million or 41 percent potential overrun of the estimate."

7. ESTIMATING RELATIONSHIP METHODS

a. Introduction

The Estimating Relationship methods derive their source from the observation that costs of systems seem to correlate with performance variables. These independent variables, often called explanatory variables, permit the use of regression analysis to describe an assumed or hypothesized underlying mechanism relating the variables and cost. That is, cost as a dependent variable is assumed to be a function of the variables plus an error term. The Cost Estimating Relationship (CER) approach to cost estimating, also called parametric cost estimating, is widely accepted and, even for complex functions, easy to apply. This ease of application makes it natural to attempt the use of regression techniques and estimating relationships in risk analysis. The approach is to attempt to discover acquisition program characteristics to which numbers can be assigned as values of explanatory variables, which can then be correlated with historically demonstrated need for management reserve. The user of this method performs a regression analysis using "actual" management reserve as a dependent variable to determine a function of the explanatory variables so that he can estimate management reserve requirements for programs not in his data base.

A basic difference between the use of such a parametric approach for cost estimating and for risk analysis is that the explanatory variables selected in the risk analysis application surveyed for this handbook do not represent performance, or output, variables. Therefore, the hypothesized mechanism described by the derived function of explanatory variables has less intuitive justification.

A danger inherent in the use of this method is the failure to understand the relative relationship of the explanatory variables to the dependent variable. The selection of different ranges for each explanatory variable in itself modifies the relative effect and when, as in one application, the values of the separate explanatory variables are simply added to form a "rating," hidden assumptions are made which should be explicitly justified since they are easily questionable. The application of the more sophisticated regression technique known as stepwise regression might obtain quite different results. Despite these concerns, the technique has received acceptance.

b. The Model

The application of this technique is described in [8]. Four contract characteristics which exhibit degrees of uncertainty are evaluated by program management personnel. Each characteristic is assigned a number on a different scale for each characteristic. The four characteristics used are Engineering Complexity (zero to five), Contractor Proficiency/Experience (zero to three), Degree of System Definitization (zero to three), and Multiple Users (zero or one). The sum of these numerics is entered as the value X in

$$y = 0.192 - 0.037\,X + .009\,X^2$$

This formula finds the percentage management reserve requirement, y. The model is said to be usable only for X values between 2 and 10. Lower values indicate lack of need for management reserve. Experience on which the estimating relationship is based indicates that programs with 9 or 10 ratings (management reserve over 50 percent) were given frequent enough review to ensure adequate funding.

c. Implementation

The values assigned to each of the four program characteristics are determined by using an existing definition for each

level or value. To that degree, a certain amount of standardization is maintained. Presumably, the same person evaluating a number of different programs could feel confident in the consistency of his evaluations and resultant management reserves. On the other hand, it is not clear that different management offices would evaluate a common list of programs to arrive at similar area levels or summations. A question needing settlement before this method can be used with confidence is one of relative scaling among characteristics. The assignment of a "three" instead of a "one" to a program characteristic variable has the same effect for each, yet it is not clear that such should be the case.

d. Outputs

The output of this form of risk analysis is a percentage management reserve. According to [8], the historic management reserves used consisted of contract cost growths--defined as percentage above initial contract cost--to accommodate for unknown program events and for alteration of the system's physical or functional characteristics. Since the data were collected on the contract level, it seems that such validity as this method possesses relates to the restricted level of contract management reserve.

8. THE RISK FACTOR METHOD

a. The Model

For this method, an engineering form WBS is preferable from the point of view of obtaining expert assessment of the WBS element cost growth possibilities. This method is more intuitive than the other methods discussed earlier; less demand is made on the expert who, in practice, is often a cost analyst providing an assessment for a broad range of activities and technologies. No consideration of the entire range of possible costs is requested, and thus a bias may be built in. There can also be a tendency to

give less care in supplying the cost factor than is used in supplying the difficult assessment needed for other methods. In addition, factors are by definition multiplicative; that is, they will be used to obtain upper limits of cost by applying the factors to the WBS cost element point estimates. Few analysts will claim that they can supply the factors used in this method to an accuracy of more than two decimal places, therefore, the precision of these statements is necessarily low, especially with highly aggregated or high-cost WBS elements. Furthermore, little insight is available through this type of information for determining critical program areas. Despite these concerns, the technique is widely accepted.

b. Implementation

The primary source of this method is [18].

A Work Breakdown Structure, described in [21], is an outline form or hierarchy of engineering tasks or budget categories for describing a program.

In the use of this method, each Work Breakdown Structure (WBS) element identified in a material development program is analyzed to determine the specific subelements that will contribute to uncertainty in the establishment of the cost of execution of that element. A risk factor is then assigned for each identified WBS element as a number increased over 1 by an amount representing an accumulation of estimated proportional increases in the cost of that element as a result of probable changes to it during its development. These increases are determined by a judgement based on the analyst's expectation of cost growth.

If the specific program's work has not yet been identified in sufficient detail, risk factors are assigned on the basis of larger aggregates of work, system components, or system types, depending upon the detail available. Specific considerations to be included in this judgement are:

(1) Requirement to develop an item not possible with existing technology.

(2) Requirement to develop a completely new item.

(3) Whether major integration effort will be necessary.

The following paragraphs supply an example from [18].

Assume that the development of a single channel, selectable frequency, FM VHF radio transceiver is desired, as in Figure 12, page IV-21.

1. Prepare an engineering cost estimate (as in Table [F-2] for each element in the WBS.

2. Compute a risk factor for each WBS element.

3. Multiply the risk factor by the element cost (enter the results as column (c) of Table [F-2]).

Table F-2

COMPUTATIONAL METHODOLOGY

FM VHF Radio WBS Elements	a Engineering Cost Est.,$	b Risk Factor	c Revised Estimate
Packaging	21,000	1.34	28,140
Tansmitter	18,000	1.13	20,340
Receiver	12,000	1.04	12,480
Power Supply	12,000	1.20	14,400
Synthesizer	25,000	1.35	33,750
(Freq Mult Reduc)	(10,000)	1.02	(10,200)
(Oscillator)	(15,000)	1.57	(23,550)
TOTAL	$88,000		$109,110

In the example, risk factors are developed for each component using the following reasoning.

1. Examining individual components results in the conclusion that, except for the oscillator, engineering cost estimates

(considering only the component by itself, or internal effects) are certain. The design effort is not significantly different from previously accomplished work. To determine the contribution to the risk factor for the oscillator due to internal effects, costs for comparable oscillators from three other systems are examined.

2. The design process is highly complex and iterative, often causing interaction effects among system components. Design changes to the oscillator can induce design changes in the power supply and packaging areas which in turn could have design impact on the oscillator again. For each component the contribution to the risk factor due to external effects is assigned (taking into account all potential external cost contributors, such as interaction and funding delays, and the probabilities of occurrence of these costs).

"The risk factor for each component is a composite factor determined by combining the contributions of both internal and external effects. For example, it is estimated that the total of internal and external forces on the oscillator will result in a 57% increase over the engineering cost estimate. Therefore, the risk factor is 1.57 (column, b, Table [F-2]). The other risk factors are similarly general." [18]

c. Outputs

The example continues:

The program risk assessment cost can now be compiled as illustrated in Table [F-2].

Subsequently, program work is broken out by year for programming and budgeting purposes using the original engineering estimate, the risk factors and revised estimates, as shown in Table F-3. The unparenthesized number is the year's original element estimate and the parenthesized number is the product of the unparenthesized one and the appropriate risk factor.

Table [F-3]

Annual Cost and Risk Cost

WBS ELEMENT	ESTIMATED COSTS ($K)				
	YEAR 1	YEAR 2	YEAR 3	YEAR 4	TOTAL
Packaging	3(4.02)	4(5.36)	6(8.04)	8(10.72)	21(28.14)
Transmitter	6(6.78)	6(6.78)	3(3.39)	3(3.39)	18(20.34)
Receiver	4(4.16)	4(4.16)	2(2.08)	2(2.08)	12(12.48)
Power Supply	4(4.80)	4(4.80)	2(2.40)	2(2.40)	12(14.40)
Synthesizer	10(14.05)	6(7.77)	5(6.75)	4(5.18)	25(33.75)
TOTALS	27(33.81)	24(28.87)	18(22.66)	19(23.77)	88(109.11)

(NOTE: Revised estimate figures are adjacent to the engineering estimate for each year.)

On the basis of the above calculations, the budget request for year 1 would be $33.8K, and the programming amounts for the subsequent outyears would be $28.87K, $22.66K, and $23.77K, respectively, for a program total of $109.11K.

The sole applicability of risk factors assessment is for cost estimating and budgeting. The type and quality of information derived is unsuitable for other uses.

LIST OF REFERENCES

1. Antunes, Moore, Ed., Army Programs Decision Risk Analysis (DRA) Handbook, U.S. Army Logistics Management Center, Fort Lee, VA, (DARCOM Handbook 11-1.1-79), 1979, (#).

2. Atzinger, E. et al, Compendium on Risk Analysis Techniques, DARCOM Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, 1972, (AD 746245), (LD 28463).

3. Barclay, Brown, Kelly, Peterson, Phillips, and Selvidge, Handbook for Decision Analysis, Decisions and Designs Inc., McLean, VA, 1977, (#).

4. Brown, R.V., Kahr, A.S., and Peterson, C., Decision Analysis for the Manager, Halt, Rinehart & Winston, New York, NY, 1974, (#).

5. Cost Uncertainty/Management Reserve Analysis, Cost Management and Technology Division, Directorate of Cost Analysis, Deputy for Comptroller, Armament Division, Eglin AFB, FL, January 1982, (#).

6. Cost Uncertainty/Risk Analysis, Headquarters Air Force Systems Command, Andrews AFB, MD, June 1981, (#).

7. Crawford, L.P., LCDR USN, A Case Study in Risk Decision Analysis, Defense Systems Management College, Fort Belvoir, VA 1973, (AD A046651), (LD 32644A).

8. Evriviades, M., Management Reserve Cost Estimating Relationship, Cost Estimating and Analysis Division, Directorate of Cost Analysis, Comptroller, Hanscom AFB, MA, March 1980, (#).

9. Feiler, A.M., The TRANSIM V Manual, Volume I, Introduction to TRANSIM V, UCLA-ENG-7848, UCLA School of Engineering and Applied Science, Pasadena, CA., September 1978, (ADA059925)

10. Feiler, A.M., The TRANSIM V Manual, Volume II, TRANSIM User's Manual, UCLA-ENG-7855, UCLA School of Engineering and Applied Science, Pasadena, CA., September 1978 (ADA 060397)

11. Hillier, F.S., and Lieberman, G.J., Operations Research, Second Edition, Holden-Day, Inc., San Francisco, CA, 1974, (#).

No AD/LD Number for this Document.

12. Hwang, J.D., Analysis of Risk for the Material Acquisition Process, Part I - Fundamentals, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1970, (AD 715 394), (LD 25933).

13. Hwang, J.D., Analysis of Risk for the Material Acquisition Process, Part II - Utility Theory, U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL, 1971, (AD 747365), (LD25933).

14. Hwang, J.D., and Kodani, H.M., An Impact Assessment Algorith for R&D Project Risk Analysis, U.S. Army Air Mobility R&D Laboratory, Ames Research Center, Moffett Field, CA, October 1973, (#).

15. Jordan, H.R., and Klein, M.R., An Application of Subjective Probabilities to the Problem of Uncertainty in Cost Analysis, Office of the Chief of Naval Operations, Resource Analysis Group, Systems Analysis Division (OP-96D), Washington, D.C., November 1975 (ADA 105780)

16. Keeney, R.L., and Raiffa, H., Decisions with Multiple Objectives: Preferences and Value Tradeoffs, John Wiley & Sons, New York, NY, 1976, (#).

17. Kraemer, G.T., "Quick and Effective Risk Analysis", Transaction of the AACE Annual Meeting, 21st, pg. 177; Morgantown, WV, 1977, (#).

18. "Letter of Instruction (LOI) for Implementation of RDT&E Cost Realism for Current and Future Development Programs", Office of the Deputy Chief of Staff for Research, Development and Acquisition, Department of the Army, Washington, D.C., 6 March 1975, (#).

19. Martin, M.D., A Conceptual Cost Model for Uncertainty Parameters Affecting Negotiated, Sole-Source, Development Contracts, University of Oklahoma, Norman, OK, 1971, (AD A035482), (LD 37971A).

20. McNichols, G.R., On the Treatment of Uncertainty in Parametric Costing, The School of Engineering and Applied Science, The George Washington University, Washington, D.C., February 1976, (#).

21. Military Standard, Work Breakdown Structures for Defense Material Items, 25 April 1975, (MIL-STD-881A), (#).

22. Moeller, G.L., Venture Evaluation and Review Technique, Decision Models Directorate, U.S. Army Armament Material Readiness Command, Rock Island, IL, November 1979, (AD A076 600).

23. RISNET Analyst's Guide, John M. Cockerham & Associates, Inc., Huntsville, AL., (#)

24. Total Risk Assessing Cost Estimate (TRACE) Guide, John M. Cockerham & Associates, Huntsville, AL., September 1979, (#)

25. Wheeler, C.F., Contract Pricing Techniques to Pass Government Cost Credibility Tests - Contractor Viewpoint, Martin-Marietta Aerospace, (#).

26. Wilder, J.J., and Black, R., "Using Moments in Cost Risk Analysis," in Martin, Rowe, Sherman, Ed., Proceedings: Management of Risk and Uncertainty in the Acquisition of Major Programs, University of Southern California, Colorado Springs, CO, 1981, (#).

27. Wilder, J.J., and Black, R., "Determining Cost Uncertainty in Bottoms-Up Estimating", Paper presented at the 1982 Federal Acquisition Research Symposium, The George Washington University, Washington, D.C., May 1982 (#).

28. Williams, J.B., CAPT USAF, An Analysis of Risk Assessment Within Aeronautical Systems Division, The School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, OH, 1971, (LD 27458).

29. Williams, C. and Crawford, G., Analysis of Subjective Judgment Matrices, The RAND Corporation, Santa Monica, CA, 1980 (#).

30. Worm, G.H., Application of Risk Analysis in the Acquisition of Major Weapon Systems, Clemson University, Department of Mathematical Sciences, Clemson, SC, 1980, (LD 49124A).

31. Worm, G.H., Applied Risk Analysis with Dependence Among Cost Components, Clemson University, Clemson, S.C., November 1981 (#)

APPENDIX G

PRESENTATION OF RESULTS

1. GENERAL

As a decision influencing document, a risk assessment can have many uses. It may be a reference for subsidiary decisions, for reevaluations as time passes, and a basis for management studies that will be undertaken in the future. Assessments that substantiate major decisions, such as the Decision Risk Analyses used at major milestones, and those that provide the basis for budget submissions will be under increasingly critical review as more and higher levels of management become familiar with risk analysis tools. Managers, therefore, should be interested in appropriately rigorous documentation of risk assessments.

Since a risk assessment is an effort to apply scientific methods to objective and subjective information, the framework in which the assessment is described should enhance and enforce the logic of scientific inquiry. The method of scientific inquiry in matters relating to management is often termed systems analysis or operations research. Thus the general approaches and organization of a systems analysis or operations research report are appropriate to a risk assessment.

2. REPORT INTRODUCTION

Each report should begin with an introduction and synopsis of the sections to follow. The first item should identify the document requiring the assessment. Essentials of problem formulation, key decisions to be made, alternatives to be considered, a brief description of analytical approach, findings, and major recommendations should appear. This section may be entitled Executive Summary and should serve the purpose of briefly communicating enough information for an executive to understand the issues, have confidence in the analysis, identify the conclusions, and determine the decision implications.

3. <u>PROBLEM FORMULATION</u>

This section should describe the decision for which the assessment is being performed. The section should describe the program in summary fashion and provide details relative to the decision to be made. If the decision is selection of one or more technical alternatives, this section should describe the characteristics they incorporate--both those that provide orientation and those that relate to the decision.

4. <u>APPROACH</u>

The second section of the main report should describe in moderate detail the general methodology to be used in the analysis. An assessment is not completed by the exercise of a piece of software, yet most network analyses depend heavily on some piece of software. The software should be completely identified by name and version number. Any unusual updates or features employed should be described. The methods of representing uncertainty that are actually in the model--if a model limitation--should be explained and the implications of the limitation discussed. If the software can accommodate more than one method of representation (e.g., PDF or explicit list of probabilities, or various different PDF's), then the reasons for selection of the utilized method and some discussion of pros and cons should be included. For networks, the number of activities (arcs) and decision points (nodes) should be given. Problems in modeling and compromises for purposes of simplifications of modeling should be discussed.

a. <u>Assumptions</u>. Major assumptions should be identified. This is easy for some assumptions, but frequently an analyst is unaware of assumptions. A concentrated effort should be made during the assessment process so that all assumptions may be identified and addressed.

b. Data Collection. A subsection should be devoted to describing the categories of information needed for the analysis, the organizational sources of the information, and the techniques used to obtain it. The techniques could include any of the face-to-face techniques described in Appendix D or, for example, questionnaires. If simplifications to data are made they should be discussed as well as the implications of the simplifications.[1] An Appendix should list the data and the data sources by name, and rationales for the data where appropriate (i.e., where it represents subjective judgment.)

c. Evaluation. The output of the model or analysis must be described in sufficient detail so that the analytical approach to its evaluation can be made clear. There should be a description of what the possible combinations and ranges of outputs can imply to the program manager.

d. Summary. The discussion of the Approach can be the same in many different assessment reports using the same techniques, but it should still be included for purposes of report completeness.

5. FINDINGS

The findings are factual statements such as, "The analysis shows that there will be a P percent probability of funds in excess of the budget being needed to be ready for milestone X on schedule", or, "The analysis shows that decision point Y has the highest criticality index of all decision points. This is because activities P, Q, and R, all having high uncertainty, require successful development of component J". Some findings, while not major, deserve discussion in that they emphatically confirm or contradict conventional wisdom.

---

[1]For example, one study in the bibliography uses most likely values (taken from a baseline cost estimate) and derives the extreme values by applying the same standard multipliers against all most likely values. The PDF form used was the

a. Sensitivity Analysis. A sensitivity analysis determines the effects of assumptions on the findings. Thus, the more searchingly identified the assumptions, the more clarifying are the sensitivity analysis and the more convincing are the assessment's findings and recommendations. It is important that assumptions be identified early in the assessment process, since reformulation of the model to analyze extreme values of an assumption may cause major disruption. Not only are the effects of selected counter-assumptions important, but perhaps even more important are the boundaries in the regions of assumptions at which major findings and major recommendations change. For example, although a manager may not be able to give precise values for numeric assumptions, he will want to know whether they lie well within a region in which decisions do not change.

b. Recommendations. A proper systems analysis or operations research effort is concerned with assisting management in decision making. This statement has some perhaps not-so-obvious implications, for instance:

- Analysts should seek to identify, and even propose, feasible alternatives.

- Analysts should discuss, evaluate, and recommend one or more alternatives.

- Analysts should clearly delineate the points at which assumption variation modifies findings and recommendations and make those modifications explicit.

- Analysts should include implementation methods in considering alternatives, so that they feasibily accommodate environmental realities.

---

triangular distribution. This procedure of using standard multipliers substantially weakens the analysis, and its implications should be discussed.

- o Analysts should remember that a manager wants more than a digested set of facts; therefore it will be necessary to make assertive proposals.

6. GENERAL

The documentation guidelines discussed in this chapter apply to an extensive risk assessment. The limited application of risk assessment for budgeting requires somewhat modified documentation standards. The same observation can be made about applicability of some of the more elaborate risk assessment techniques, yet both the elaborate techniques and the extensive report may give rise to budgeting decisions.

Higher review levels in the services and DOD will become increasingly interested in evaluating the basis of budgets incorporating risk assessment concepts. Deputy Secretary Carlucci encouraged the Services to incorporate technical risk consideration into budgeting, and the Army has been doing so for some years. Congress is aware of TRACE and of DOD's interest in the other miliary services' adopting similar techniques; thus it is likely that the techniques will come under increasing use and scrutiny. The documentation will provide confidence in the basis of budgets' incorporation of risk concepts. Objective evaluation and acceptance is then more likely. To ensure support for budgets an abbreviated documentation <u>should</u> cover each major subject area discussed above and <u>must</u> address the analytic method by which findings are reached.

APPENDIX H

POLICY DIRECTIVES

1. GENERAL

This Appendix summarizes and annotates the directives of higher authorities and the military Services.

These directives were identified by reviewing the system acquistion and management directives of OMB, DOD, the Army, the Air Force, and the Navy, and noting all references which deal specifically with risk analysis. Some references imply the need for risk analysis, but do not explicitly state such requirement. Although additional documents were reviewed, only those listed were found to contain material relevant to risk analysis.

2. HIGHER LEVEL REQUIREMENTS

This section lists excerpts, and comments briefly on OMB and DOD policies and directives relating to risk assessment.

a. Office of Management and Budget

OMB Circular A-109. Major System Acquisition (5 April 1976)

Para 7. "Each agency acquiring major systems should... tailor an acquisition strategy for each program....The strategy should typically include...methods for analyzing and evaluating contractor and Government risks."

b. Department of Defense

DOD Directive (DODD) 5000.1. Major System Acquisition (29 March 1982)

Para C.2.C.(3). To achieve program stability, DOD components will "estimate and budget realistically, and fund adequately, procurement (research, development, and production), logistics and manpower for major systems.

Para E.4.C.(1)(a). This paragraph states that it may be reasonable to delay Milestone II decision until some development efforts are accomplished in order to "reduce risk and uncertainty before the committment to a major increase in the application of resources toward full-scale development is made."

Para E.8. "Commensurate with risk, such approaches (to reduce acquisition time) as developing separate alternatives in high-risk areas;... should be encouraged."

DODI 5000.2 Major Systems Acquisition Procedures (March 8, 1983).

No references to risk analysis appear in body of text, however, Paragraphs D.3.e.(1)(a) and D.3.e.(2)(a) refer to the need for System Concept Papers (SCP's) and Decision Coordinating Papers (DCP's) to establish and identify goals, thresholds, and threshold ranges [emphasis supplied], thus recognizing the concept of risk.

Enclosure (4) Format for SCP and DCP.

"VIII. Technological Risks of Selected Alternative. For Milestone I (SCP), identify key areas of technological risk which must be reduced by R&D and validated by T&E before Milestone II. For Milestone II (DCP), discuss T&E results that show all significant risk areas have been resolved. Also for Milestone II, verify that technology is in hand and also engineering (rather than experimental) effort remains."

DODI 5000.38. Production Readiness Reviews (24 January 1979)

Para A.2. "The objective of a PRR [Program Readiness Review] is to verify that the production, design, planning, and associated preparations for a system have progressed to the point where a production commitment can be made without incurring unacceptable risks of breaching thresholds of schedule, performance, cost, or other established criteria."

Para E.4. "The DPESO (DOD Product Engineering Services Office) independent production readiness assessment will consist of objective conclusions based on the findings of the PRR and other investigations. This assessment will identify potential problem areas which constitute production, cost, or schedule risks. Each risk will be expressed in terms of its relative magnitude and potential consequences." [emphasis supplied]

DODI 7041.3. Economic Analyses and Program Evaluation for Resource Management (October 19, 1972)

Enclosure (2)

Para B.7. "Risk/Uncertainty Analysis. Risk assessments will be made to determine the expectation or probability that program/project objectives will be realized by following a specific course of action with constraints of time, cost, and technical performance. [emphasis supplied] Actual costs and outputs of many DOD projects differ from those expected at the time of decision. For those cases, and in particular for major weapon systems covered by a Selected Acquisition Review Report or subject to review by the Defense System Acquisition Review Committee (DSARC), the impact which could result from this variability should be evaluated."

Para B.7.a. "Independent parametric cost estimates can provide an early test of the reasonableness of cost estimates. Independent parametric cost estimates will be made at key decision points for major weapon systems, e.g., during concept formulation and prior to making major commitments of funds for development and production. These estimates generally consider cost at high levels of aggregation and are predicated on actual historical costs encountered in like or similar programs. As such, they incorporate costs for expected uncertainties on the average. (1) Costs should be derived by parametric techniques and expressed as feasible ranges in terms of the parameters which drive them. It is

most important that estimates be presented as cost ranges related to the probable values of system parameters, characteristics, or attributes which are determined by costs. [emphasis supplied] (2) These estimates will be available for each DSARC review. Parametric estimates will be derived independent of functional, program manager or contractor influence. (3) When the independent parametric cost estimate differs from the program manager's current estimate, the latter estimate will be used for economic analysis/program evaluations. Once a program estimate is established as a baseline, a program/project manager will manage his program within that limitation. (4) The program manager's current estimate will be an assessment of the ultimate cost expected for a program/project including undefinitized contingencies. [emphasis supplied] As such, the program manager's current estimate should be relatively stable over long periods of time and not change with small incremental changes to the approved program, funding changes, or financial fluctuations. To the extent possible, schedules and funding should be structured to accommodate program uncertainties and unforeseen problems." [emphasis supplied]

Para B.7.b. "Special degrees of risk/uncertainty associated with a particular program/project, may be pointed out quantitatively in an analysis and used for program review purposes. Probability estimates can be developed by testing the sensitivity of key variables on estimated costs and performance. The probability that each of the possible cost or output estimates may be realized should be discussed narratively when there is no basis for a quantitative estimate." [emphasis supplied]

Para B.7.c. Estimates will be expressed in terms of performance thresholds, goals, or ranges. Program/project estimates will include the limits within which ultimate program cost and technical performance is expected to fall."

3. SERVICE REQUIREMENTS

a. U.S. ARMY

The following Army directives require or imply a need for risk assessment as shown by excerpts and editorial condensations.

o Army Regulation 70-1 Army Material Acquisition (Draft, 14 May 1981).

Para 4-6.a.1. Advanced, engineering and operational systems development is to "conduct system advanced development in promising areas in order to resolve key technical, readiness, cost and/or schedule uncertainties before entering the full-scale Development Phase. Such efforts should be accomplished with low-level programs and full realization of technical risks."

Para 4-10.a. "In general, PEP [Producibility Engineering and Planning] measures include... performing risk analysis of new manufacturing processes... When a high-risk producibility area is determined during PEP which normal design tradeoff... cannot provide for the same performance..., and a requirement is established for special-purpose or unique tooling and/or processes, a Manufacturing Technology Development effort (RDTE funded) should be initiated. If a high-risk area manufacturing technique that is generic in nature... is identified, a manufacturing Methods and Technology effort (MM&T procurement-funded) should be considered."

Para 5-2.c.(2). The Management Plan for System Development will be supported by management plans for risk analysis among other plans.

Para 5-2.c.(3). The Financial Plan for System Development will include "established program cost controls or cost parameters including design-to-cost goals and TRACE."

Para 8-5.f. "Risk analysis and management, which includes elements of risk identification, planning, analysis, evaluation, resolution, and review, will be completed for computer resources prior to Milestone II. Computer resource risk analysis and management will be closely coordinated with the requirements validation effort and the overall systems engineering effort to assure that the risks associated with achieving validated cost, schedule, and technical performance requirements are identified and assessed in advance, are within acceptable thresholds, and are continuously monitored and reported during subsequent development."

o Army Regulation (AR) 70-10. Research and Development, Test and Evaluation During Development and Acquisition of Materiel (29 August 1975).

Para 1-4.(3). "During the full-scale development phase and prior to the first major production decision, the DT (Development Test) accomplished will be sufficiently adequate to insure ... that all significant design problems (including compatibility, interoperability, safety, Reliability, Availability, and Maintainability (RAM), and supportability considerations) have been identified, and that solutions to the above problems are in hand.

Para 2-4.c.(5). "As the development cycle continues into DT/OT [Development Test/Opertional Test] II, the uncertainty in these estimates should be reduced and, by the completion of DT/OT III, sufficient testing should have been accomplished so that the uncertainty in estimating the final system performance will be relatively small, ..."

Para 2-5.e. "EDT (Engineering Development Test) is conducted by the contractor and/or the material developer with the primary objective of influencing material design." ... "The purposes of EDT are to...(3) Eliminate as many technical and design risks as possible or to determine the extent to which they are manageable."

o Department of the Army Pamphlet (DA-Pam) 11-2. Research and Development Cost Guide for Army Materiel Systems (May 1976).

Para 3.5. Range Versus Point Estimates. a. "The use of a point estimate does not reflect the uncertainty associated with the estimate. It also implies that it is a precise cost. For these reasons, a range of costs should be provided based on the inherent cost estimating uncertainty. The level at which the ranges can be provided is dependent upon the level at which the costs are estimated. Within the limitations imposed by the data base and cost estimating approach employed, ranges should be presented at the highest aggregate level.

"b. In addition, an analysis should be made of the sensitivity of projected costs to all critical assumptions. This should include factors such as the impact of changes in performance characteristics, changes in configuration to meet performance requirements, schedule alternations and alternative production processes."

o DA-Pam 11-3. Investment Cost Guide for Army Materiel Systems (April 1976) Exactly the same words as above.

o DA-Pam 11-4. Operating and Support Cost Guide for Army Materiel Systems (April 1976). Exactly the same words as above.

o Development Acquisition and Readiness Command Regulation (DARCOM-R) 11-1. Systems Analysis

Para 4.d. "...RA and DRA are applied to alternative courses of action and permit structuring models that address the uncertainty of cost, schedule, and performance of systems." [RA and DRA mean risk analysis and decision risk analysis respectively.]

Para 5.c. "An IE and DRA will be completed prior to each decision milestone in major programs which will involve .... (ASARC) or .... (DSARC) proceedings, or in non-major

programs for which DA has retained in-process review (IPR) approval authority. For non-major systems, an ASARC will be completed prior to each IPR "unless it is clear that no appreciable time, cost, or performance risk is associated with the decision." [IE means Independent Estimate; ASARC, Army Systems Acquisition Review Council; DSARC, Defense Systems Acquisition Review Council; DA, Department of the Army.]

Para 6.d. "Each commander of an R&D or MR Command will: 3) ensure that IE's and DRA's are initiated for the decision points described in paragraph 5c." [MR means Materiel Readiness.]

Appendix D-Decision Risk Analysis Guidelines

1. Define the problem.
   b. Establish the decision maker's preferences for tradeoffs between cost, schedule, and/or performance.
2. Establish the alternatives.
3. Define the events.
4. Collect the data.
5. Determine the program risks.
6. Select the best alternatives.
7. Perform sensitivity analysis.
8. Communicate the results.

o DARCOM-R 11-27. Life Cycle Management of DARCOM Materiel Chapter 3. Section II - Procedures

Para 3-8.b. "The justifications for by-passing activities and events are...(2) That the risk for omitting the actions is reasonable when considering the savings of time and resources."

Para 3-8.c. "When requesting the shortening of schedules, the PM will request DARCOM approval and submit a statement including the assessment of risks incurred in shortened plan compared to base plan."

o AR-11-28. Economic Analysis and Program Evaluation for Resource Management

Chapter 1

Para 1-6.p. "Where costs for research and development represent a significant portion of total program cost, the decision to conduct research will be supported by an economic analysis which identifies potential follow-on cost, savings resulting from the research and development, degree of risk or uncertainty in achieving results, availability of resources, assessment of current technology, and identification of constraints.

Chapter 2

Para 2-2.b. "The structure of analysis will also contain, when appropriate, an assessment of the relative risk or uncertainty of success associated with each of the alternatives considered, including the status quo when applicable."

o AR-15-14. Boards, Commissions and Committees - Systems Acquisition Review Council Procedures

Page 4-3. This paragraph states that risk analysis will be presented to HQDA 2 months before ASARC.

o AR-70-1. Army Research, Development and Acquisition (29 August 1975)

Para 1-7.o. "Technical uncertainty will be continuously assessed. Progressive commitments of resources will be made only when confidence in program outcome is sufficiently high to warrant going ahead."

Para 2-2.a. In conceptual phase, "critical technical issues, operational issues, and logistical support problems are identified for resolution in subsequent phases in order to minimize future development risks."

Para 2-15.a. "Test and evaluation will be conducted as early as possible and throughout the material acquisition process to reduce acquisition risks...."

Para 2-15.c(4). DT will be used to "demonstrate, during the Full Scale Development Phase and prior to the first major production decision, that the DT accomplished is adequate to insure that engineering is reasonably complete; that all significant design problems...have been identified; and that solutions to the above problems are in hand."

Para 4-1a. "Department of the Army policy for advanced, engineering, and operational systems development is to--(1) Conduct system advanced development in promising areas using either single or competitive approaches in order to resolve key technical, cost and/or schedule uncertainties before entering Full-Scale Development Phase. Such efforts should be accomplished with low-level programs and full realization of technical risks."

Para 4-1m. "Program sufficient funds to provide for the technical uncertainty inherent in the development effort."

Para 4-1af. "Give consideration to requiring development contractors to provide second sources for high technical risk subsystems/components, whether or not the development contract is sole source or competitive."

o AR 71-9. Material Objectives and Requirements (Final Draft 26 Feb 1981).

Para 1-5 "Test and Evaluation will begin as early as possible in the acquisition cycle and will be conducted throughout the system acquisition process as necessary to assess acquisition risks ..."

Para 3-4.k. "Army R&D organizations are to take the following specific actions with respect to the STOG (Science and Technology Objectives Guide): (1) Perform assessments

with respect to overall feasibility, estimated cost, time, risks, and possible technological solution alternatives within mission areas.... (4) Communicate directly with the user proponents on topics such as ....(c) Informing the user proponent of estimated solution alternatives, risks, time and estimated manpower and dollar costs, so that the user can perform an affordability and/or tradeoff assessment."

Para 4-2.d.(7)(b). "...Even when pursuing a single concept, competition should be considered in development of the concept or component development in order to minimize risk of hardware development."

o Letter of Instruction (LOI) for Implementation of RD&TE Cost Realism for Current and Future Development Programs, DAMA-PPM-P, (6 March 1975).

Para 3.a. Defines TRACE as "the expected total cost over a specified period of a material development program computed on the basis of the costs of accomplishing the work elements of the program's Work Breakdown Structure..., and including specific provisions for the statistical estimation of probable program costs otherwise indeterminate. The TRACE should be that estimate having a 50/50 chance of producing either a cost overrun or an underrun."

Para 3.d. Defines risk factor as "as assessment of the probable expansion of that work necessitated by changes in other elements of the program or by changes in the work itself."

Para 3.e. Defines risk analysis as "an analysis conducted as a part of the cost estimation process for a material development program in which risk factors are constructed encompassing probable cost increases to a program work element expected during its development, ..."

Para 4.b. "Specifically, the TRACE should include consideration of the following:

(1) Technical design changes to correct deficiencies.

(2) Design changes to accommodate nominal revisions in component performance.

(3) Rescheduling to work around technical problems and nominal budetary limitation.

(4) Additional testing to verify design corrections.

(5) Additional hardware to support design modifications.

(6) Non-neglegent human error."

Para 4.c. "The TRACE will be the material development program cost estimate used for program planning and justification."

Para 5.a.(1). "It is to be emphasized that the purpose of the TRACE is not to create unjustified 'reserves.' Rather, the TRACE is to produce realistic cost estimates of what probably will be required on a development program."

Para 5.a.(2). "In the conduct of risk analysis, each Work Breakdown Structure (WBS) element identified in a materiel development program will be analyzed to determine the specific sub-elements that will contribute to uncertainty in the establishment of the cost of execution of that element. A risk factor will then be constructed for each identified WBS element as a number increased over 1 by an amount representing an accumulation of estimated proportional increases in the cost of that element as a result of probable changes to it during its development. These increases will be adjusted by a judgmental determination of just how likely it is that each will occur."

Para 5.a.(3). "If the specific program work has not yet been identified in sufficient detail, risk factors will be assigned on the basis of larger aggregates of work, system

components, or system types, depending upon the detail available. In such cases, risk factors will be constructed judgmentally in full consideration of the engineering, producibility and budgetary aspects of the program. Specific considerations to be included in this judgment are:

(a) Whether the program requires the development of an item not directly supported as feasible by existing technology.

(b) Whether the program requires the development of an item substantially different from those previously developed.

(c) Whether major integration effort will be necessary even though individual components may in themselves be considered to involve low risk."

Para 5.b. "TRACE computation. The risk factors will be multiplied by the engineering cost estimate at the appropriate level of the WBS. The appropriate level will depend not only on the level of design detail available, but also on the degree of component and subsystem interaction. In those circumstances where a design change of a given component or subsystem appears likely to propagate and cause a design change of a related component or subsystem, a higher level of aggregation will also be required to maintain statistical validity of the overall estimate by including these interdependent effects. The risk factors, when applied at the appropriate level of the WBS as explained above, can be statistically combined to produce the TRACE."

Para 6.a. "The costs of specific program work scheduled for accomplishment during a particular year will be estimated using the TRACE methodology. The TRACE thus compiled for the program 'work-year' will be the amount submitted to OSD and the Congress as required for the program for that year. The funds representing the difference between the TRACE and the engineering cost estimate will not be carried in a separate

category, but rather will be allocated to the various tasks to which the funds will most likely be applied."

Para 6.b. "To allow for the possibility of cost savings to allow more precise managerial control of funds appropriated for program execution during a budget year, only that amount reflecting the basic (engineering) cost estimated for that year (i.e., the engineering cost estimate consisting of the work costs prior to multiplication by the respective risk factors) will be released initially to the manager for program execution. The remainder of the appropriated program funds will be held in deferral by the DCSRDA and released to the manager only upon request and approval of a justified need. Program funds (obligated authority) not required in the current year program will be considered for designation to the Congress as a means to reduce the requirement for new obligational authority is the subsequent year's budget. Other use of such unneeded funds may be authorized by the DCSRDA, as appropriate."

o Letter of Instruction (LOI) for Implementation of the Total Risk Assessing Cost Estimate for Production (TRACE-P) (6 October 1982).

Para 4.b. "The TRACE-P estimate will include consideration of the risks in the following categories; these are explained at Enclosure 1.

(1) Threat Uncertainty
(2) Management
(3) Materials/Purchased Parts
(4) Facilities/Equipment
(5) Labor
(6) Design Changes
(7) Producibility
(8) Performance"

Para 4.c. "Specifically excluded from the estimating of TRACE-P expected risk costs are possible increases that may result from one or more of the following causes:

(1) Quantity changes

(2) Performance improvement to meet an increased threat

(3) Poor management

(4) Inadequate funding in the early years

(5) Unknown unknowns"

Para 4.g. "TRACE-P funds will be held in deferral by the DCSRDA and released to the program/project/product manager only upon request and approval of a justified need."

o RDA Cost Realism - Future Development Programs (12 July 1974) DASA Letter

"Our estimate should be unbiased so that we have about an even chance of either going over or under it."

"It is submitted that cost overruns will continue to be a way of life until adequate recognition is given to the impact of program uncertainty in estimating costs" [emphasis in original].

"...it remains the fundamental nature of RDT&E ... to involve the unknown. These unknowns invariably lead to cost requirements which cannot be individually forseen at the outset of a development--yet their cumulative impact can be seen in retrospect with all the assuredness of the laws of probability" [emphasis in original].

"The provision of flexibility in the funding plan baseline-cost estimates should reflect these probable additional costs."

o Total Risk Assessing Cost Estimate (TRACE) Deferrals - DRCDEPC letter, (17 April 1978).

Para 2. "A program TRACE refers to its total expected RDT&E costs as agreed to by the ASARC/DSARC. The definition applies both to annual costs and development costs. Funds in excess of the baseline or engineering costs for a particular fiscal year are deferred at the beginning of that year by

HQDA (DCSRDA) pending the occurrence of predicted (but unprogrammed) events upon which the funds were based. These funds will be released to the Project Manager (PM) upon his demonstration that they are necessary to offset the cost of such events. If a program adjustment is made during the programming and budgeting cycle, the entire scope of the program should be reevaluated and the risk factor recomputed. TRACE funds identified for deferral in the outyears should not be reduced in order to increase the baseline portion if that adjustment is made merely to offset a decrement to the program or to increase its scope."

<u>Para 3</u>. "The funds released from HQDA are expected to be adequate for execution of the known estimated engineering costs. It is DARCOM policy to expect that the PM manage his total program with the funds authorized. Risk contingency (TRACE deferral) funds will be released only if technical/design problems and/or unexpected delays materialize, and this fact is completely demonstrated in the release request. Release requires both DCSRDA and ASA (R&D) approval."

<u>Para 4</u>. "The PM can indicate at any time that TRACE deferral funds will not be needed. If deferral has not been released by the fifth quarter of availability, the PM will be given the opportunity to justify retention of such deferrals considering that the work upon which they were based may have continued into the second year. Otherwise, disposition of the funds will be determined by the DCSRDA in coordination with the ASA (RL&LD) and CDR DARCOM. The PM may request that the unneeded TRACE deferral funds be released for expanded scope of work in the same weapons systems; however, that request will be evaluated with other unfinanced requirements in other programs."

b. <u>US Air Force</u>

The following Air Force directives address consideration of program risk as revealed by excerpt or editorial summarization.

o Air Force Regulation AFR 173-11, Independent Cost Analysis Program (12 Dec 1980)

Para 6. Definition and Scope of the Independent Cost Analysis (ICA)

Para 6.f. "Will contain a detailed risk assessment to include risk related to the cost estimating techniques employed and with technical and schedule uncertainties that may have an impact on cost estimates. It will also include sensitivity analyses of critical assumptions and cost during parameters."

Para 7.e. "For cost elements with a high degree of uncertainty, the ICA will provide sensitivity analysis using frequency distributions or ranges of cost. The probability distributions used to prepare range estimates, as well as the proper assumptions, must be provided. Prediction intervals around cost estimating relationships (CERs) or Monte Carlo simulations will be used as proper in quantifying risk." [emphasis supplied]

Para 9.d. "The ISR will address the potential risk in the program office estimate by identifying 'risk' areas and their probable and possible cost impact." [ISR means Independent Schedule Review]

o AFR 70-15. Source Selection Policy and Procedures

Para 1-4.d. "The source selection process shall focus adequate attention on the program risk and uncertainties during solicitation, proposed evaluation, and selection phases.

(1) Offerors should not be penalized for the identification of risk associated with their proposals. Proposals should be credited when realistic approaches for risk resolution are provided.

(2) The procuring activity shall prepare an independent risk assessment before receipt of proposals, to facilitate risk analysis evaluation.

Para 2-2.c(3). "It [the evaluation criteria] must address those high risks and technical uncertainties, which were identified by the offerors and the Government as 'known-unknowns' during the conceptual phase. An indication should also be provided of the relative importance of each criterion for later use in the solicitation.

Para 2-4.d. "... Risk analysis is a part of the evaluation process, and risk assessment for each proposal must be included in all reports to the SSAC [Source Selection Advisory Council] and SSA [Source Selection Authority]. Technical risk, as pertains to each proposal, should be rated based on the offeror's risk assessment and the credibility of his proposed approach for eliminating or avoiding such risks."

Para 3-2.a.(2). "The solicitation should ... include a discussion of known or potential risks, where there is reason to believe that the potential offerors are not aware of the risks."

Para 3-7.e. "The offerors must be required to submit a risk analysis as part of their proposal which also identifies risk areas and which furnishes an insight to the evaluator as to how the offeror intends to resolve these risks and the alternatives to overcoming the high risk approaches. (1) In order to aid the evaluator in performing the risk analysis, the procuring activity should prepare an independent risk assessment prior to receipt of proposals."

Para 3-8.b.(5). This paragraph states that the SSA must determine cost/price risk inherent in each proposal.

Attachment 4

VIII. Risk Analysis

This paragraph lists risk analysis documentation format.

o AFR 800-3. Engineering for Defense Systems, (17 June 1977).

Para 4.b. [In the validation phase]"...certain technical aspects may need to be intensified, such as technical and cost risk reduction, obtaining a best mix of technical requirements, and other considerations or thresholds as may be described in the PMD."

Para 6.f. The AFSC "programs their research and development (R&D) projects to develop and improve systems engineering methods and techniques (system cost effectiveness, risk assessment, technical performance measurement, etc.)."

o AFR 800-8. ILS Program, (7 February 1980).

Para 5.r. "Risk analysis and assessment and tradeoff analyses will be conducted, using the latest data available."

o AFR 800-9. Manufacturing Management for Air Force Acquisitions (1 October 1979).

Para 2.c. "In the manufacturing assessment of system and design alternatives the program manager will: (1) Consider the relationship between several factors (such as producibility, manufacturing risks, productivity ....) and evaluate their impact on the minimum essential performance requirements."

Attachment 1. Extracts from DODD 5000.34, 31 October 1977.

Para D.5. "... Production risks, which should be identified as early as possible in the acquisition cycle, shall be reduced to acceptable levels prior to production decision."

o Aeronautical Systems Division Regulation (ASDR) 173-1 Aeronautical Systems Division Cost Analysis Program (21 October 1981).

Attachment 5: Cost Estimate Risk Assessment Guidelines

Para 1. "...The purpose of the risk analysis described below is to alert decision makers to:

a. Inputs or assumptions where a percent change in an input or assumption value would make at least one half that percent change in the total estimate.

b. Areas of uncertainty at the time the estimate was prepared....

Para 2. "Generally, risk assessments must be prepared so that while not all possible areas of risk are addressed, the overall amount of risk of cost growth can be assessed by review of the several highest risk areas identified and discussed."

Para 3. "The risks of cost increase over the estimates to be addressed will be primarily those associated with estimating methods are [sic] available data/information limitations. The risks of strikes, major test or technical approach failures, directed program changes, etc., are not to be addressed."

c. US Navy

The following Navy directives address program evaluation including some mention of risk evaluation. Excerpt and editorial summaries are presented.

o Secretary of the Navy Instruction (SECNAVINST) 5000.1B System Acquisition (8 April 1983).

Para 5.g. Management Principles and Objectives. The instruction presents as a management principle "applying established or evolving technology having a high probability

of success. High technical risks may be taken if an extraordinary payoff potential can be demonstrated."

Para 6. "Acquisition Categories. A program is a candidate: ACATIIS designation by SECNAV,... if it is of special SECNAV interest, ...because of... a history of technical, cost and schedule problems," or "an extraordinary strategy and/or risks."

Para 8. "Decision Milestones. Milestones and phases will be tailored to fit each program to reduce acquisition time and cost, consistent with risk."

Para 8.b. "Milestone II. It should be demonstrated to the decision authority that technical and operational risks have been reduced to acceptable levels."

Enclosure (2) Management Considerations

Para 3. "Acquisition Time. Programs shall be planned for system development within the shortest time reasonable. At each milestone, schedule alternatives and inherent risks shall be assessed. Methods to be considered include combination or omission of acquisition phases; smooth transition to production; single concept development; preplanned product improvement; use of alternatives in high risk areas; experimental prototyping of critical components; or coordination of common purchases between different programs."

Para 10. "Test and Evaluation. Test and evaluation are an integral part of the acquisition process to assess technical performance and risks,... Schedules shall be flexible to allow retest or reevaluation as necessary prior to a milestone, and shall avoid duplication commensurate with risk."

Para 14. "Acquisition Risks. Technical, operational, schedule, and cost risks shall be identified as early as possible and assessed continuously. They shall be disclosed in full to the decision authority and addressed realistically at each

milestone. A management reserve bases on the cost risk shall be established for ACAT I and IIS programs."

Enclosure (4) Navy Decision Coordinating Paper (NDCP) Format

Para 1. "Risks. State program risk, including at Milestone I, technological risks to be reduced by R&D and validated by T&E before Milestone II; at Milestone II, demonstrate that all significant risk areas have been resolved and verify that technology is in hand and only engineering (rather than experimental) effort remains; at Milestone III, identify any shortfalls in technical evaluation (TECHEVAL) and OPEVAL results against thresholds.

o Naval Material Command Instruction (NAVMATINST) 5000.19D Acquisition Program Reviews and Appraisal Within the Naval Materiel Command (16 February 1982).

Para 4a. "... this instruction requires a consistent, timely, independent assessment of major programs in order to ensure that they are technically, financially, administratively and logistically sound. The (independent) assessment is to provide a high degree of confidence that the program is, in fact, sound and executable."

Para 4.b. "The ARB's [Acquisition Review Board's] purpose is to ensure that the presentation accurately reflects the Chief of Naval Material position, that the program itself is logical and executable from a business/programmatic and technological standpoint and complies with applicable tasking from higher authority. "

o Naval Material Command Instruction (NAVMATINST) 5000.29A Acquisition Strategy Paper (6 May 1983).

Para 2. The Acquisition Strategy Paper shall discuss Risk Analysis in Section II - Risk Analysis Enclsoure (1) "specify the major problems or risk areas which have been considered in selection of an acquisition strategy and which must be overcome to achieve the basic program objectives."

Para. 3. Section III - Strategy to Achieve Objectives and Implementation shall contain the "Risk Management Plan for dealing with areas (technical, costs, schedule and logistics)," and the business management plan of "incentives to achieve program thresholds including methods to control costs," and "incentives to improve reliability and reduce support costs."

o Naval Air Systems Command Instruction (NAVAIRINST) 7131.1 Management of Research, Development, Test and Evaluation, Navy (RDT&E,N) Risk Cost Estimate Funding (21 April 1983).

Para 4. "Procedures. BCE (baseline cost estimate) funds budgeted and approved for a project will be allocated to the requiring financial manager (RFM) in accordance with established procedures. It is expected that BCE funds will be adequate for the execution of known requirements and that the RFMs will manage their programs within funds authorized. RCE (risk costs estimate) funds will be held by the RDT&E Budget Division (AIR-803) and released only it technical, design, or other unexpected problems arise, and the facts are completely justified. Release of RCE funds requires the approval of both the cognizant Deputy Commander/assistant commander and the Commander, Naval Air Systems Command (AIR-00). Specific procedures follow:

Para 4.a. "AIR-803 will allocate BCE funds to RFMs in accordance with established procedures, using NAVMAT Form 2198/1, Administering Office Allocation Distribution Research, Development, Test and Evaluation, Navy by Program Year. RCE funds will be allocated to a separate project unit under AIR-803 cognizance."

Para 4.b. "To obtain the release of RCE funds, the RFM must submit justification in the format enclosure (1) and forward it by memorandum to AIR-803. The request will include a financial status of the program, complete justification for the use of RCE funds and an impact statement explaining the effect if RCE funds are not released."

Para 4.c. "AIR-803 will review the request for accuracy and substance and forward it to the cognizant Deputy Commander/assistant commander or return it to the RFM as appropriate."

Para 4.d. "Upon the recommendation of the Deputy Commander or cognizant assistant commander, the request will be forwarded to AIR-00."

Para 4.e. "AIR-00 will approve/disapprove the request and return it to AIR-803 for appropriate action."

Para 4.f. "Disapproved requests will be returned to the RFM's by AIR-803. For approved requests, AIR-803 will prepare the necessary allocation documents reprogramming the RCE funds to a project unit under the cognizance of the RFM. RFM's will be repsonsible for establishing a task area code designated 'RCE' in the Chart of Accounts and directing RCE funds to this task area. Managers are required to use the limited indicator (block 18 of NAVMAT Form 7132/7, Project Directive) in conjunction with the RCE task area."

Para 4.g. "RFM's may indicate at any time that RCE funds are not needed, in which case they will be reprogrammed to satisfy other urgent RDT&E,N requirements. RCE funds not used by RFM's will be considered for reprogramming after 12 months from the beginning of the fiscal year for which they were appropriated. The reprogramming of RCE funds will require prior approval of AIR-OO and must follow established reprogramming procedures for the RDT&E,N appropriation."

o Naval Sea Systems Command Instruction (NAVSEAINST) 5000.3A. Acquisition Program Appraisal Within the Naval Sea Systems Command (25 May 1982).

Enclosure 1: ARB Procedures

Para 3. Section III - Strategy to Achieve Objectives and Implementation shall contain the "Risk Management Plan for dealing with areas (technical, costs, schedule and

logistics)," and the business management plan of "incentives to achieve program thresholds including methods to control costs," and "incentives to improve reliability and reduce support costs."

Para 5.b. Presentation. "Technical, financial, logistic, and administrative issues and program risks should be highlighted and discussed." [Beyond this reference, the document consists only of administrative procedures and reporting or briefing formats.]

o Naval Electronic Systems Command Instruction (NAVELEXINST) 5000.13A. Acquisition Program Review and Reporting Within the Naval Electronic Systems Command. (19 July 1982).

Enclosure (2)

5. "The Oversight Group team will prepare a report on significant risks, ... and recommended or initiated actions and will provide a ... copy of this report to the Acquisition Manager."

APPENDIX I

BUDGET POLICIES INCORPORATING RISK ASSESSMENT

This Appendix provides information on two widely known Army budget policies incorporating risk assessment, TRACE and TRACE-P. The TRACE policies appear separately because, although governing only Army budget matters, they have become widely known in all three Services, and Carlucci Initiative Number 11 directs that, "...each service shall review the TRACE concept and either adopt it or produce an alternative for their [sic] use." As starting points for the other services' own policies, an understanding of these concepts will assist in formulation and implementation of similar policies in the other two services.

1. TRACE

In a 1974 memorandum [7], Norman Augustine, the then Assistant Secretary of the Army for Research and Development, identified the need to reduce the order of magnitude of cost errors certain to occur when R&D budgets are formulated for only those eventualities that are foreseen. The Assistant Secretary desired the funding of "certain uncertainties" and proposed the "risk factor" method. The memorandum provided the complete concept of TRACE, including general guidelines on administration. In March 1975, the Army Deputy Chief of Staff for Research, Development, and Acquisition (DCSRDA) published [6], providing the administrative details of the TRACE system and outlining the "risk factor" methodology. Although the methodology lacks mathematical rigor, it provides the Army with a simple, understandable method providing grossly for the "known unknowns". Prior to the DCSRDA directive, various risk assessment tools existed; however, the DCSRDA directive initiated establishment of Army and Military Service policy for attempting to determine the effects of technical risk on cost growth. The directive stated that uncertainty should be considered an essential element of weapons systems acquisition.

Reference [6] does not restrict analysts to the "risk factor" method but allows the use of "other generally accepted methodologies". Some projects have gone into more detail, applying probabilistic event analyses and networks simulations.[1] One of the professional services contractors who had assisted Augustine in development of his concept briefed various Congressmen and Congressional staff members on the theory and practice of TRACE. The briefings, some of which took place in 1979, were generally well received.[2] Because Army budget submissions have included TRACE's on selected programs for a number of years including those following the cited briefings, there seems no reason to believe that the Congress is dissatisfied with the Army's implementation of TRACE.

The essential elements of TRACE are the following:

- o An analytical assessment of technical risk resulting in a TRACE, intended to be at the level at which there is as great a liklihood of overrun as underrun.
- o Review, within the Army, of both the program manager's Baseline Cost Estimate (BCE) and of the TRACE estimate, which is expected to be the larger of the two.
- o Submission of the TRACE, as modified within the Department of the Army, to DOD and Congress as the Program Objectives Memorandum (POM) or Budget estimate.

---

1 McGinnis, LTC, USA, and Kirschbaum, Capt., USAF; "Trace Risk Assessment and Program Execution"; Defense Systems Management College, Fort Belvoir, Va., Dec. 1981.

2 Letter to the author from John M. Cockerham and Associates, Inc. Huntsville, Ala., dated 21 September 1982.

- Upon approval of the Budget, release to the PM of only the amount of the BCE. Deferral of the difference between the TRACE and the BCE (known as the TRACE margin or TRACE deferral) at the DA level (DCSRDA).

- Release of any portion of the TRACE deferral to the PM only upon "request and approval of a justified need".

While the foregoing points are made in the TRACE LOI itself, reference [4] directs that TRACE deferrals identified for a given program may not be reprogrammed except under highly circumscribed conditions.

2. TRACE-P

Believing the TRACE concept and risk assessment to be worthwhile tools, and finding that significant cost growth occurs when systems transition from R&D into production, analysts at The Army Procurement Research Office (APRO) determined that a risk assessment/budgeting method should be devised to control that problem. The Army investigators identified for each program a set of 11 "uncertainty elements" which are treated as cost elements and which are said to be normally associated with production transition. Some (e.g., facilities) are the same items as are found in some aggregation of the BCE. Others (e.g., design stability) are more difficult to relate to BCE cost elements. The methodology [8] recommends assigning three cost values to each element, assigning a distribution to each, finding the distribution mean of each, and subtracting the relevant BCE element costs from the mean costs to determine the TRACE-P deferral. Note that in contrast to the policy with TRACE for R&D, this reference recommends use of the mean instead of the median (identical to the 50 percent confidence level), however it also states that confidence levels for TRACE-P estimates can be obtained if other supplementary techniques are used.

The Army DCSRDA has not yet approved a TRACE-P procedure, pending further evaluation; however, the Development and Readi-

ness Command Comptroller has signed a DARCOM Letter of Instruction [5] which defines a modified methodology (compared to that in [8]) and the same administrative procedures for TRACE-P as for TRACE for R&D.

LIST OF REFERENCES

1. Grover, P.E., and Schneickert, G.D., MAJ USA, Total Risk Assessing Cost Estimate (TRACE): A Field Survey, Systems and Cost Analysis Department, School of Logistics Science, U.S. Army Logistics Management Center, Fort Lee, VA, (#).

2. House of Representatives, Committee on Appropriations, Report on the Department of Defense Appropriation Bill, 1983, (#) pp. 100-101, 140-145.

3. Lilge, R.W., Total Risk Assessing Cost Estimate (TRACE): An Evaluation, U.S. Army Research and Development Command, Systems and Cost Analysis Division, St. Louis, MO, February 1979, (AD B034709). (LD 44065A)

4. Lunn, MG Robert J., "Total Risk Assessing Cost Estimate (TRACE) Deferrals", Department of the Army, DRCDE-PC, Alexandria, VA, 17 April 1978, (#).

5. "Letter of Instruction (LOI) for Implementation of the Total Risk Assessing Cost Estimate for Production (TRACE-P)", Headquarters, U.S. Army Material Development and Readiness Command, Alexandria, VA, 6 October 1982, (#).

6. "Letter of Instruction (LOI) for Implementation of RDT&E Cost Realism for Current and Future Development Programs", Office of the Deputy Chief of Staff for Research, Development and Acquisition, Department of the Army, Washington, DC, ALM-63-4476-H, 6 March 1975, (#).

7. "Memorandum for the Director of the Army Staff, Subject: RDT&E Cost Realism--Future Development Programs", Department of the Army, Office of the Assistant Secretary, Washington, D.C. 12 July, 1974 (#).

8. Norton M., Abeyta, R., and Grover, P., Production Risk Assessing Methodology (PRAM), U.S. Army Procurement Research Office, U.S. Army Material Systems Analysis Activity, Fort Lee, Va, May 1982, (#).

9. Venzke, G.A., LTC USA, Implementation of Risk Assessment in the Total Risk Assessing Cost Estimate (TRACE), U.S. Army War College, Carlisle Barracks, PA, 1977, (LD 39206A).

10. Worm, G.H., Application of Risk Analysis in the Acquisition of Major Weapon Systems, Clemson University, Department of Mathematical Sciences, Clemson, SC, 1980, (#). (LD 49124A).

(#) no AD/LD number for this document.

APPENDIX J

CENTERS OF RESEARCH

The following is a list of some of the more prominent organizations engaged in research on, and accomplishment of, acquisition program risk assessment.

1. Department of Defense

   - Defense Systems Management College, Fort Belvoir, VA.

2. U.S. Army

   - U.S. Army Logistics Management Center, Fort Lee, VA
   - Army Procurement Research Office, U.S. Army Systems Analysis Activity, Fort Lee, VA
   - DARCOM Material Systems Analysis Activity, Aberdeen Proving Ground, MD.
   - U.S. Army Armament Command, Rock Island Arsenal, Rock Island, IL.
   - U.S. Army Construction Engineering Research Laboratory, Champaign, IL.
   - U.S. Army Aviation Research and Development Command, St. Louis, MO.
   - U.S. Army Material Readiness Command, Systems Analysis Directorate, Rock Island, IL.
   - U.S. Army Research Office, Research Triangle Park, N.C
   - U.S. Army Missile Command, Redstone Arsenal, AL.
   - U.S. Army Electronics Command, Systems Analysis Office, Fort Monmouth, N.J.
   - U.S. Army War College, Carlisle Barracks, PA.
   - Red River Army Depot, Texarkana, TX.
   - U.S. Army Aviation Systems Command, St. Louis, MO.

3. U.S. AIR FORCE

- Air Command and Staff College, Maxwell AFB, AL.
- School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, OH.
- The School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson, AFB, OH.
- Air Force Business Management Research Center, Wright-Patterson AFB, OH.
- Air War College, Maxwell AFB, AL.

4. U.S. NAVY

- Navy Office for Acquisition Research, Naval Material Command Headquarters, (MAT-08P), Washington, DC.

5. CIVILIAN - ACADEMIC

- Carnegie-Mellon University, Pittsburg, PA.
- Northwestern University, Evanston, IL.
- The Pennsylvania State University, University Park, PA.
- Operations Research Center, University of California, Berkeley, CA.
- University of Oklahoma, Norman, OK.
- University of Southern California, Colorado Springs, CO.
- Clemson University, Department of Mathematical Sciences, Clemson, SC.

6. CIVILIAN - CORPORATE

- Hughes Aircraft Company
- Decisions and Design, Inc., McLean, VA.
- General Research Corporation, Santa Barbara, CA.
- Decision Research, Eugene, OR.
- Martin-Marietta Corp., Orlando, FL.

- Mathematica, Princeton, NJ.
- System Development Corporation, McLean, VA.
- Meridian Corp., Falls Church, VA.
- The Rand Corporation, Santa Monica, CA.
- Grumman Aerospace Corporation Operations Analysis, New York
- LOG/AN Inc., Los Angeles, CA.
- JMCA & Associates, Huntsville, AL.
- Management Consulting and Research, Inc., McLean, Va.

APPENDIX K

APPLICATION TO CONTRACT STRUCTURE

Any method providing cost risk in terms of a cumulative distribution function can be used in contract share ratio determination as discussed in [1]. The reference employs a contract cost model including target cost, target price, and profit. The program manager selects a point above which the contractor should assume full risk and less than which the government and contractor share. He selects the point based on his decision that the contractor should assume full risk above a cost representing a confidence level he determines. Figure [K-1] illustrates such an application. For the example in Figure [K-1], cumulative probability is determined indirectly by assuming the overall cost to be representable by a normal distribution, so that the mean plus a number of standard deviations determines the cumulative probability. If the normal distribution is considered too gross an approximation, any distribution with skew could be used, and the policy decision can be based on the 50th and a higher selected confidence level, for example the 90th. In other words, the contractor would assume full risk above the higher level, and the government and contractor share cost between that and the point at which there is an equal likelihood of cost being overrun or underrun. The ratio itself is determined by using the Defense Acquisition Regulations Weighted Guidelines to fix the profit at the 50th percentile point.

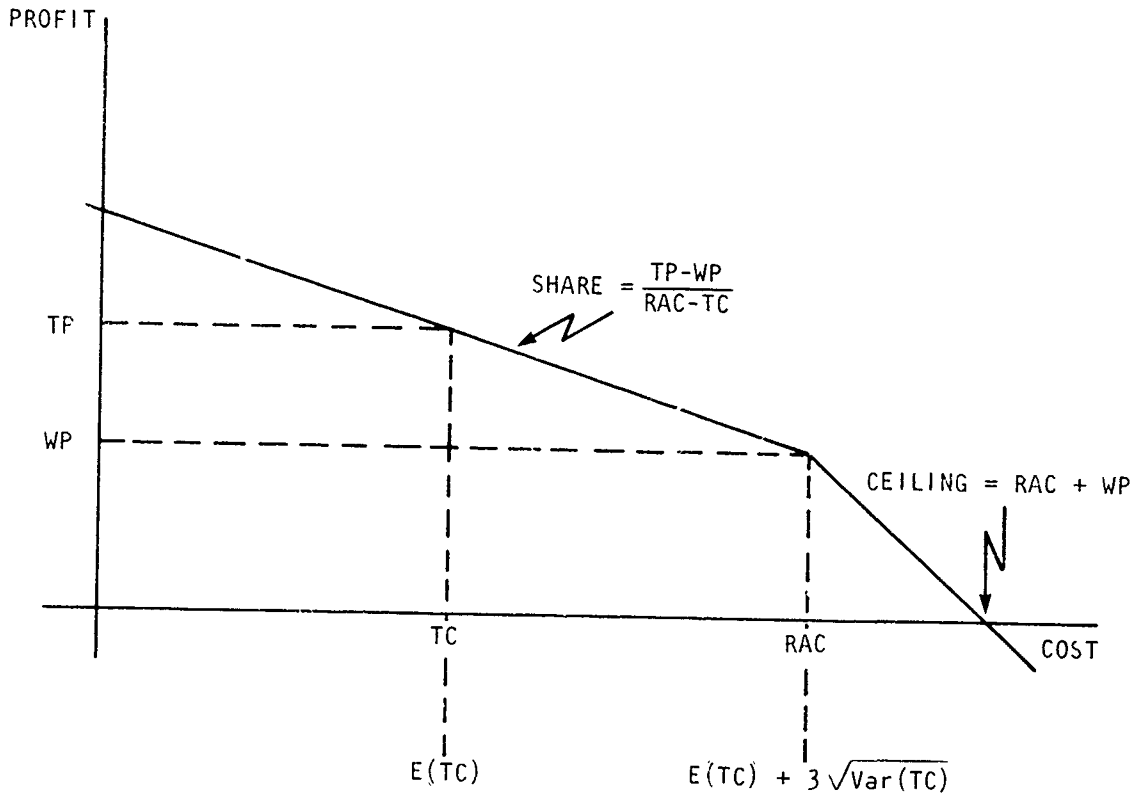


Figure K-1
INCENTIVE CONTRACT

The symbols in the figure are defined:

TP is Target Profit
WP is Warranted Profit
TC is Target Cost
RAC is Risk Analysis Cost

Here E(TC) is Expected (mean) Target Cost and 3 $\sqrt{VAR\ (TC)}$ is three times the standard deviation of Target Cost. A variation of this diagram can be used to investigate the cost to the government of share ratio changes.

While Figure K-1 is not model output in the sense of a computer printout, it exemplifies an application of risk assessment output information.

LIST OF REFERENCES

1. Worm, G.H., "An Application of Risk Analysis - Uses, Problems, and Pitfalls", Proceedings of Management of Risk and Uncertainty in the Acquisition of Major Programs, U.S. Air Force Academy, Colorado Spring, CO., February 1981, (#).

(#) No AD/LD number for this document

APPENDIX L

APPLICATIONS OF METHODS OUTPUTS

Chapters II and III discussed the types of outputs produced by risk assessments and how they could be used in program management decisions. Chapter IV summarized the assessment methods and briefly presented the output of each. Table L-1 summarizes the connection of method to application via method output. By reading across from a specific method at the left, the reader finds an entry under the category of information which the method supplies from routine output, from improved systems, or in limited fashion. The reader then follows down the column to the intersection with the row extending from a selected application. An X entry signals that such information is useful in decisions relating to that application.[1]

In considering Table L-1, it helps to realize that some of the columns identify types of information inherent in others. For example, a probability density function inherently includes an intuitive understanding of skew and the coefficient of variation, respectively. The CDF inherently includes confidence level information.

It can be seen from Table L-1 that the mean as a category of information is not used in decision categories by the methods discussed herein. This is because most output distributions will be skewed and the mean does not specify a confidence level for such distributions. For the mean to be of value requires more intensive understanding of the decision analysis [4], [5]. The information wanted, however, lies in the other output categories.

---

[1]Assignment of output to application is admittedly subjective and subject to change as researchers explore new applications. Managers must evaluate these assignments by their own criteria.

In Table L-1 entries under the heading INTERNAL indicated that risk information is provided on program elements. Entries under COMPREHENSIVE indicate that such information is provided on the program as a whole.

The joint cumulative distribution function shows the cumulative probability of any pair of two variables, thus permitting the manager to perform a trade-off between the two. For example, if cost and schedule have a joint cumulative distribution, the manager can determine the probability that cost will be less than or equal to X *and* development time less than or equal to Y. If he prefers a lower cost, he can see that there is a lower probability of cost less than or equal to (X-a) *and* development time less than or equal to Y. Alternatively, he can find a point (X-a) and (Y+b) such that the probability of cost less than or equal to (X-a) and development time less than or equal to (Y+b) is the same as for his original pair, X and Y.

METHOD	PROBABILITY DENSITY FUNCTION INTERNAL	PROBABILITY DENSITY FUNCTION COMPR *	CUMULATIVE DISTRIBUTION FUNCTION INTERNAL	CUMULATIVE DISTRIBUTION FUNCTION COMPR	JOINT CUMULATIVE DISTRIBUTION FUNCTION	MEAN	STANDARD ERROR (STANDARD DEVIATION)	SKEW	COEFFICIENT OF VARIATION	CONFIDENCE LEVEL	CRITICALITY	ORGANIZATION RESPONSIBLE	DATES FOR CRITICALITY	MULTI-RESOURCE STATUS & PROJECTION	PROBLEM IDENTIFICATION	MULTIPLE STATUS	MANAGEMENT RESERVE
NETWORK	R	R	R	R	R	R	R	R	R	R	R	I	I	I	I	I	R
MOMENTS	L	L	L	L		R	I	L	I	L							I
DECISION ANALYSIS	I	I	I	I	I	I	I	I	I	I					I		I
WBS SIMULATION	I	I		I		R	R			R					I		
GRAPHICS	L	L	L	L		R		L		L							L
ESTIMATING RELATIONSHIP																	R
RISK FACTOR																	R
APPLICATION																	
TECHNICAL ALTERNATIVE	X	X	X		X		X	X		X	X		X		X	X	
MAJOR PLANS, DECISION	X	X	X		X		X	X		X	X		X	·	X	X	
SOURCE SELECTION		X		X	X		X	X	X	X							
ACQUISITION STRATEGY	X	X	X	X	X		X	X		X							
POM/BUDGET			X	X				X	X	X							X
MANAGEMENT CONTROL	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
CONTRACT STRUCTURE				X			X		X	X							

NOTES R ROUTINE PROVISION *COMPR COMPREHENSIVE
I IMPROVED PROVISION
L LIMITED PROVISION

TABLE L-1

APPLICATIONS
OF
METHODS OUTPUT

LIST OF REFERENCES

1. Barclay, S., et al, Handbook for Decision Analysis, Decisions and Design, Inc., McLean, VA, September 1977 (#).

2. Brown, R.V., Kahr, A.S., Peterson, C., Decision Analysis for the Manager, Holt, Rinehart and Winston, New York, Chicago, San Francisco, Atlanta, Dallas, Montreal, Toronto, London, Sydney, 1974 (#).

3. Hwang, J.D., Analysis of Risk for the Materiel Acquisition Process, Part I - Fundamentals, Systems Analysis Directorate, U.S. Army Weapons Commoand, Rock Island, IL, November 1970 (AD 715 394).

4. Hwang, J.D., Analysis of Risk for the Materiel Acquisition Process, Part II - Utility Theory, Systems Analysis Directorate, U.S. Army Weapons Command, Rock Island, IL, May 1971 (AD 747 365).

5. Keeney, R.L., and Raiffa, H., Decisions with Multiple Objectives, John Wiley & Sons, New York, Santa Barbara, London, Sydney, Toronto, 1976 (#).

(#) No AD/LD number for this document

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Risk Assessment Techniques A Handbook for Program Management Personnel		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER ISI V-3836-05
7. AUTHOR(s) Information Spectrum, Inc.		8. CONTRACT OR GRANT NUMBER(s) MDA 903-82-G-0055/003
9. PERFORMING ORGANIZATION NAME AND ADDRESS Information Spectrum, Inc. 1745 S. Jefferson Davis Highway Arlington, VA 22202		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Systems Management College Fort Belvoir, VA 22060		12. REPORT DATE July 1983
		13. NUMBER OF PAGES 228
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

"A" Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Risk Assessment, Risk Analysis, Quantitative Techniques, Program Management, Budgeting for Risk.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The primary objectives of this handbook were to make the reader aware of the risk assessment techniques being used by Department of Defense organizations, to alert the reader to the advantages and disadvantages of these techniques, and to assist him in applying risk assessment to his acquisition program.

The handbook is intended to be a practical guide and reference for program management personnel - not a textbook dealing with the theories supporting risk

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

analysis, nor a user's manual for applying any particular techniques. Thus, the handbook is organized to address, in summary, the most important questions to program management personnel, i.e., Why do a risk assessment? What techniques are available? How do I select and implement a technique? These questions are answered in the first six chapters. This summary-level material is supported by a series of Appendices that provide detailed discussions of the techniques in use, the service regulations pertaining to risk assessments, a glossary of terms, and a structured bibliography.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983-410-377